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TABLE OF CONTENTS

SOIL MANAGEMENT SECTION PAGE

Maximum Wheat Yields - Farm Scale Experiences
- B. Schnell
Soil Characteristics to Consider When Evaluating Sites for Pothole Consolidation
- N.D. MacAlpine and G. Shaw
Drainage Survey Schools - An Overview and Evaluation
- B.W. English and N. MacAlpine
Crop Residue Management in Conservation Tillage Systems
- L. Samson
Soil Conservation - A Practical Viewpoint
- R.C. McNabb
The Effect of Soil Erosion on Soil Productivity: Preliminary Findings of a Two Year Study
- R. Morrison-Ives and C.F. Shaykewich
Size Distribution and Stability of Dry Surface Soil Aggregates and Their Effect on Wind Erosion Potential in Westborne, R.M.
- M.N. Langman
Inter-Crop Seeding of Fall Rye for Control of Soil Erosion on Row Crop Land - The P.E.I./Manitoba Experience
- B. Graham, J.M. Sadler and H.G. Vass
The Modification of Groundwater Systems to Enhance the Land Base
- L.R. Gray
Soil Water - Soil Temperature Interactions in the Germination and Emergence of Corn
- H.W. Cutforth, C.F. Shaykewich and C.M. Cho
1984 Fall Moisture Map
- L. Slevinsky

SOIL CHEMISTRY AND FERTILITY SECTION

Copper and Molybdenum Nutrition of Forage Crops
- J.M. Tokarchuk and L. Loewen-Rudgers
Copper Fertilization of Wheat and Methods of Evaluations Availability of Copper to Wheat Growing on Mineral Soils
- A.O. Ridley and J.N. Kamwagha
Effects of Phosphorus Rates on Alfalfa Seed Yields
- D. Campbell and G. Bonnefoy
The Measureements of Nitrate and Nitrite in Soils by Reverse Phase HPLC
- T.C. Kuchnicki, L.P. Sarna and G.R.B. Webster

PAGE

Ionic Transport in Soil with Ion Exchange Reaction
- C.M. Cho
Maning the Most of Nitrogen Recommended Practices Resulting from Recent Research in Alberta
- D.C. Penney

SOIL CLASSIFICATION AND INTERPRETATION

Soil Physical Properties of Selected Soils on Till and Lacustrine Deposits in Manitoba
- W. Michalyna and P. Haluschak
Development of an Interpretative Classification System for Assessing the Irrigation Suitability of Soils
- R.G. Eilers
Preliminary Results of Soil Climate and Hydrology Studies in the Discontinuous Permafrost Zone near Thompson, Manitoba
- G.F. Mills, H. Veldhuis and R.G. Eilers
Transient Groundwater Flow Surrounding a Recharge - Slough in a Till Plain
- J.G. Mills and M.A. Zwarich
Canada-Manitoba Soil Survey Status Report for 1984-85
- R.E. Smith

Maximum Wheat Yields - Farm Scale Experiences

by Brad Schnell, Landmark Agro Ltd.
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During the last three years we have been working with a group of area farmers with the express purpose of achieving increased wheat yields. Our results have shown that even top producers can improve their yields significantly. How have these farmers worked towards maximizing their yields?

In working with these farmers we have developed a three point program which includes:

i.) setting crop production goals
ii.) developing a soil testing program
iii.) bringing it all together at the field level through a High Yield Wheat Club where we test the type of yields that can actually be achieved on a farm scale.

In the following presentation I will explain the importance and results of each of the above.

i) Goal setting

Before setting yield goals it is important to understand why and how goals should be set. A yield goal provides us with something to work towards. Without a goal it is unlikely that a maximum yield will be achieved. It is only through goal setting that we can consistently make improvements and actually measure our progress.

Besides providing a target, yield goals serve as a learning tool. In order to achieve maximum yields we need to learn how to control the controllable factors in crop production and work with the uncontrollable ones. There are three factors which affect maximum yields: weather, soil, and management practices. The weather can't be controlled. Soil can be controlled to a limited degree, but generally we are restricted in any structural changes we would like to make. Management is the one factor over which we have total control.

By setting yield goals each year, we learn what management techniques we must use to achieve those goals. When we are setting our goals for top yields we must also make sure we are striving for top management. If we make good, sound management decisions such as early seeding dates, improved drainage, proper fertilizer programs and top yielding varieties, we can modify the effects of the uncontrollable factors, weather and soil. Good management decisions can minimize the effects of weather and improve soil conditions.

At what level, then, should a yield goal be set? While the aim is for a maximum yield, it must also be for a profitable yield. The goal must be set in relation to both the crop and the area. It must be practical, feasible and achievable. A goal must be realistic, otherwise it defeats the purpose.

A goal should be set at a yield which is above average to near the past maximum for the area. If the goal is set at the past average the yield will often fall below the average and the average will begin to decrease. A goal which is achieved four years out of five has been set too low. In other words, the yield potential is not being maximized. To maximize production, a goal should be set at a yield which is achieved one or two years out of five.

When setting goals we have to take into consideration both growing conditions and the cost of setting low yield goals. All too often low yield goals are set because weather conditions appear unfavorable at the beginning of the growing season. Low yields are anticipated before the crop is even in the ground! While weather is an important determining factor in achieving yield goals, it should not be the overriding factor in setting those goals. If we set low goals we are cheating ourselves.

For example, based on past averages and anticipated weather, a yield goal is set at 35 bushels. Unfavorable weather does occur and reduces the yield by 10 percent or 3.5 bushels. The resulting yield is under the area average. However, what if the yield goal had been set at 45 bushels and the necessary management practices had been employed to achieve those yields? Even allowing unfavorable weather to impact 20 percent on the yield, the level of production would still have been above the average.

What are the costs of setting low yield goals? Weather is the one unknown factor in the maximum yield equation. If poor weather is anticipated and yield goals are set accordingly, the potential profit loss can be high if the poor growing conditions do not materialize. With good weather, and a higher yield goal, an additional $30 to $40 per acre could be realized.

What happens if high yield goals are set and poor weather occurs? Generally speaking, the major expense in achieving those higher goals is an additional $20 worth of fertilizer per acre. Since a portion of the unused nutrients will be available the following year, the actual cost of the higher yield goal is the cost of interest on the money invested in the additional fertilizer for one year - at 12 percent, $2 to $3.

Yes, growing conditions should be taken into consideration when setting goals but an eye must be kept on moderation. The costs of setting low yield goals can be high while the cost of setting high yield goals is usually low.

ii) Developing a soil testing program

Once goals have been set, a good soil testing program is important in order to provide a starting point for achieving those goals. There are three points concerning soil testing which need discussion:

1. the importance of soil testing
2. the confusion surrounding soil test results
3. the differences in soil testing programs

We treat soil testing as a management tool, - a very important management tool. A soil test provides a starting point. With these results in hand we know the actual soil nutrient levels and the adjustments we need to make if we hope to achieve our goal. A soil test provides some very necessary, basic information.

However, currently, a certain amount of confusion surrounds soil testing. The confusion arises from a number of things. Newspaper and magazine articles provide different ideas on interpreting soil tests. Soil testing labs appear to be sending out conflicting results. This is particularly apparent when split samples are submitted to different labs and the resulting recommendations differ, in somes cases substantially. It's these types of things that lead to confusion and frustration at the field level, and in some cases causes farmers to forgo soil testing.

In order to clear up some of the confusion it is necessary to understand the philosophies that lead to these differences in recommendations. There are three prevalent philosophies.

The first makes recommendations based on supplying the necessary supplemental nutrients to meet a specific target yield given weather and moisture conditions for a specific area.

The second bases recommendations on supplying enough nutrients to maintain the soil at its current nutrient level so that the soil nutrients are not drawn down.

The third philosophy provides recommendations which will not only supply the necessary nutrients but also build up the soil.

None of these philosophies is right or wrong. However, one philosophy may be more right than the others for a particular farming operation depending on the individual farmer's short and long range objectives.

Our High Yield Wheat Club evolved out of our interest in appraising the various philosophies at the field level with respect to maximizing wheat yields.

iii) Bringing it all together

The Landmark High Yield Wheat Club was founded on March 9, 1982 with a membership of ten top wheat producers. We set out two major objectives. The first was to produce, as a group, an average wheat yield of 60 bushels per acre. More importantly, the second goal was to determine the level of profitability associated with maximizing wheat yields. We are not trying simply to get the best yield. It must be economical as well.

As a fertilizer dealer I wanted to make sure, that if I was recommending high rates of fertilizer or inputs, those inputs would actually be of benefit to the farmer. From the farmers' point of view, they not only wanted to prove to themselves the types of yields possible, but also the profitability of those yields.

While the group as a whole has not achieved a 60 bushel average over the last three years, our yields have been substantially higher than the average for the crop district.

	Average Wheat Yields	
Year	Crop District #9	Wheat Club
1982	35.9	55.1
1983	27.5	40.2
1984	32.0*	53.8

*guesstimate - figures not available at time of writing

What type of fertilizer rates produced yields like these? The following chart shows both the levels of nutrients used by one of our members, Dave James, James Farms Ltd, Winnipeg, and the nutrient recommendations supplied by two soil testing labs for 1984.

	Target Yield Bu/acre	N	P	K	S
			(lbs)		
Man. Prov. Soil Testing Lab	48	91	38	0	0
Harris Laboratories	80	100	55	15	5
Actual	75.5*	100	48	0	5

* Yield actually achieved

This chart clearly points out the differences between soil testing labs and how those differences can affect the farmer. In the case of results from the Provincial Lab, a target yield is suggested for farmers. Here, for James Farms, the suggested target yield is 45 bushels with a maximum achievable yield of 48 bushesl under dryland conditions. Under irrigation the maximum yield is raised to 55 bushels.

The recommendations from Harris Labs, rather than suggesting a target yield, are provided on the basis of up to three target yields supplied by the farmer. He then chooses the yield for which he wishes to target. James chose to follow the Harris recommendations and set his goal at 80 bushels per acre. He came very close to the target yield. The recommended phosphorus level was not applied because James had mechanical problems with his discer.

When comparing the recommendations from the two labs, it becomes apparent that the Provincial Lab has limitations when farmers are targetting for higher yields. The members of our Wheat Club are all interested in maximizing yields. They cannot get from the Provincial Lab recommendations which meet their needs.

An argument which is often put forward against high levels of fertilizer is the Law of Diminishing Returns. After a certain point the cost of an additional unit of fertilizer is not offset by the returns from the yield increase. In our case, despite the fact that our fertilizer rates are much higher than those recommended by the Province, I do not feel that we have reached the point of diminishing returns. If we had, the Club member with the best return should have been third or fourth in yield. This has not proven to be the case. Our records show that the highest yield has also been the most profitable. The following chart bears this out.

Economic Returns

Year	Highest Yields Bu/acre	Production Costs $/bu	Net Profit $/acre
1982	67.4	2.73	65.64
1983	48.2	3.83	20.14
1984	75.5	2.22	146.25

It is my feeling that our Club members have not yet reached the upper limit on profitable wheat yields. There is still room to grow in terms of higher inputs and return on that investment. What is needed, though, is some local data which will expand the recommendations provided by the Provincial Soil Testing Lab in order to better meet the needs of top producers.

In summary, our Wheat Club has allowed our members to challenge themselves by setting goals and to put into practice management techniques which make those goals attainable. Our members have been able to test various soil testing philosophies and determine which one best suits their goals. Lastly, they have proven, on a field scale, that wheat yields can be improved and profits increased with good management, and that there is still room to maximize yields.

To recap, the keys to maximizing crop yields are:

1. setting yield goals
2. following a soil testing program
3. testing out the theories on a field scale to determine which management techniques work

SOIL CHARACTERISTICS
TO CONSIDER WHEN EVALUATING
SITES FOR POTHOLE CONSOLIDATION

by

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INTRODUCTION:

Manitoba Agriculture has been evaluating the concept of pothole consolidation for the past three years in order to encourage water conservation in the glacial till plains of Western Manitoba. Pothole Consolidation involves draining depressions and temporary potholes down to storage reservoirs in a self-contained mini-watershed usually a quarter section. It offers the advantage of using the total runoff water on the farm rather than draining it downstream to another watershed.

One reason farmers are clearing, draining and breaking potholes in Western Manitoba is to develop additional land. However, the productivity of this new land is very dependent on the soil characteristics developed in the moist environment of the pothole. In some cases, the soils in a pothole are Class 3W or 4W and the excess water hazard can be eliminated by drainage. However, in other cases, pothole soils have no agricultural potential due to salinity, groundwater seepage or poor soil structure. It is often difficult to assess the agricultural capability of pothole soils and potential problems by a simple visual assessment.

A very important step, then, in evaluating the feasibility of a pothole consolidation project is determining the potential of the pothole soils for agriculture. Since 1982, we have used the following preliminary soils guidelines to evaluate projects suggested by interested farmers.

1. Soil Test - Soil tests should be carried out on the areas to be drained and the reservoir area to determine the presence and amount of soil salinity. Vegetation surrounding the potholes also can be used as first indicators of salinity, the depth of surface water accumulating in the pothole and the depth to groundwater.
   A.E. Osborne's report, "Classification and Potential Land Use of Prairie Sloughs in the Minnedosa Area of Manitoba", catalogues the vegetation in the different zones of sloughs and relates them to different levels of soil salinity.

TABLE 1 - VEGETATION OF FRESHWATER SLOUGHS

Species	Common Name	Average Electrical Conductance (mS/cm)
A. Wet Meadow Zone		
Salix sp.	Willow	1.7 ± 1.3
Beckmannia syzigachne	Slough Grass	1.7 ± 0.6
Echinochlloa crusgalli	Barnyard Grass	-
Cirsium Arvense	Canada Thistle	-
Koeleria cristata	June Grass	2.3 ± 1.7
B. Shallow Marsh Zone		
Beckmannia syzigachne	Slough Grass	1.7 ± 0.6
Carex sp.	Sedge	1.8 ± 1.0
Typha latifolia	Cattails (occasionally)	2.3 ± 1.3
C. Deep Marsh Zone		
Typha latifolia	Cattails	2.3 ± 1.3

TABLE 2 - VEGETATION OF SALINE SLOUGHS

Species	Common Name	Average Electrical Conductance (mS/cm)
A. Wet Meadow Zone		
Agropyan repens	Quack Grass	4.7 ± 3.3
Juncus balticus	Baltic Rush	5.1 ± 2.8
Hordeum jubatum	Wild Barley	6.3 ± 4.3
Sonchus arvensis	Sow Thistle	-
	Saline Goosefoot	-
	Red Goosefoot	-
	Kochia	-
B. Shallow Marsh Zone		
Eleocharis palustris	Spike Rush	2.3 ± 1.9
Scolochloa festucacea	White Top	2.9 ± 1.9
C. Deep Marsh Zone		
Scripus acutus	Hard stem bulrush	2.9 ± 1.2
Scripus validus	Soft stem bulrush	3.8 ± 0.7
Scripus paludosus	Prairie bulrush	-

(1. - From Table 12 - "General Relationship Between Dominant Marsh Plant Species and Electrical Conductance of Surface Soils" - A.E. Osborne, Classification and Potential Land Use of Prairie Sloughs in the Minnedosa Area of Manitoba; p. 96)

Because there is limited available information on the reclamation of saline soils by drainage, it is recommended that pothole consolidation only be carried out on non-saline or weakly saline soils. Specific criteria are:

A. Pothole Should Not Be Drained If:

Surface Salinity (0-30 cm) > 2 mS/cm
and
Subsoil Salinity (30 cm-2 m) > 4mS/cm

B. With Discretion (after a dry year when surface salinity would be augmented), Pothole May Be Drained If:

Surface Salinity (0-30 cm) > 2-mS/Cm
but < 4 mS/Cm
and
Subsoil Salinity (30 cm-2 m) < 4 mS/Cm

Strongly saline areas are often supplied from groundwater sources. Drainage of these soils is costly and may not result in reclamation for annual crop production.

Extra runoff directly down to the reservoir area may result in an increase of soil salinity adjacent to the reservoir. To minimize this effect, the area around the reservoir should be seeded to high moisture using crops such as forages. The width of the forage strip, to cut off the capillary zone wicking back from the reservoir, will depend on topography and the soil type.

2. Drain Only Temporary or Recharge Potholes

Temporary potholes are ones that normally hold water until the first week of July and water depth is usually less 45 cm. These temporary potholes or Class II potholes (based on Stewart and Kantrud's classification system) generally are farmable from an agricultural soils viewpoint if drained. Class III potholes (Seasonal Ponds or Shallow Marshes) are more problematic and definitely require field investigations to decide whether they are farmable (or even drainable).

Class IV and higher wetlands (Semi-Permanent Ponds and Lakes) should not be drained. The soil under permanent water bodies often has poor soil structure and lack organic matter. Incorporation of large amounts of organic matter may be required for annual crop production. Permanent water bodies are often recharged by groundwater which makes reclamation costly and difficult.

3. Test Water Quality

The water quality of the potholes to be drained should be tested to ensure that only non-saline water is being drained. Water with a conductivity of less than $1500\mu S/cm$ can be used to irrigate most crops without detrimental effect. Water with a conductivity greater than $1500\mu S/cm$ may increase soil salinity problems in the reservoir area and irrigation is limited to salt tolerant crops.

A final consideration is the conservation consciousness of the farmer investigating pothole consolidation. Water conservation through pothole consolidation should not be used in isolation. Other land management practices that retain the maximum amount of precipitation on the land should also be adopted.

Continuous cropping, maintaining crop residues on the surface, use of tillage practices that create surface roughness, growing high moisture using crops and grassing runways will reduce surface runoffs and the cost of draining potholes.

APPENDIX

Basin Classification System - Stewart & Kantrud (1971)

Class I	Ephemeral Ponds - The low prairie dominates the basin.
Class II	Temporary Ponds - The wet meadow zone dominates the deepest portion. Low prairie is usually peripheral.
Class III	Seasonal Ponds and Lakes - The shallow marsh zone dominates the deepest part of the wetland area. Peripheral wet meadow and low prairie zones are usually present.
Class IV	Semi Permanent Ponds and Lakes - The deep marsh zone dominates the deepest part of the wetland area. Shallow-marsh, wet-meadow and low prairie are usually present and isolated marginal pockets of fen can occur.
Class V	Permanent Ponds and Lakes - The permanent open water zone dominates the deepest part of the wetland. Peripheral deep marsh, shallow marsh, wet meadow and low-prairie zones are often present and isolated pockets of fen can occur.
Class VI	Alkali Ponds and Lakes - The intermittent alkali zone dominates the deepest part of the wetland area. Peripheral shallow marsh, wet meadow and low prairie zones are usually present. A deep marsh zone is usually absent. A few fen areas are usually present.

Figure 1 - Freshwater Pothole , indicated by Willows, Cattails and Sedges plus absence of Surface Water (mid June) (Whitemud Conservation District, Subdistrict 40).

Figure 2 - Saline Slough - Dark vegetation at water's edge is hard stem bulrush. Open water indicates poor soil development. (Whitemud Conservation District, Subdistrict 40).

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3. Osborne, A.E.; 1978, Classification and Potential Land Use of Prairie Sloughs in the Minnedosa Area of Manitoba; Nat. Res. Institute, University of Manitoba, Winnipeg, Man.

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DRAINAGE SURVEY SCHOOLS:

An Overview and Evaluation

Brian W. English and Neil MacAlpine
Manitoba Agriculture

An Overview:

Training farmers to do their own survey work and ditch design is not a new idea in Manitoba. Regional Agricultural Engineers (Bob Rae and Doug Jackson) taught drainage schools in the Red River Valley in the mid '60's and mid '70's. In 1982, Wally Happychuk, an Agricultural Representative, revitalized the idea, leading to the development of an instruction manual to be used in a 3-day course.

There has been a steady increase in the demand for this course since the first four schools were organized in 1982. September and October are the ideal months for these schools since traditionally this is the time Manitoba farmers do maintenance work on the field drains as part of fall tillage.

The drainage schools are serving a specific area and drainage problem in Manitoba. (Refer to figure 1.) The schools are set up to allow the upgrading of field surface drainage on the flat lacustrine clay soils that are predominantly under cereal or special crop production. Schools are targeted for areas that are served by a network of municipal and provincial drains.

Materials presented in the course include:

(a) resources for planning drainage surveys (air photos, soil maps, drainage maps, etc.)

(b) legal responsibilities involved in drainage

(c) basic theory of profile levelling

(d) operation and use of an engineer's level

(e) designing field ditch (prepare profile to determine ditch cuts)

(f) recommended construction practices.

Essential to the success of the drainage schools is the cooperation of the local agricultural representative. The agricultural representative was responsible for selecting a suitable field for surveying practice, encouraging local participation and various other activities to ensure the success of the course.

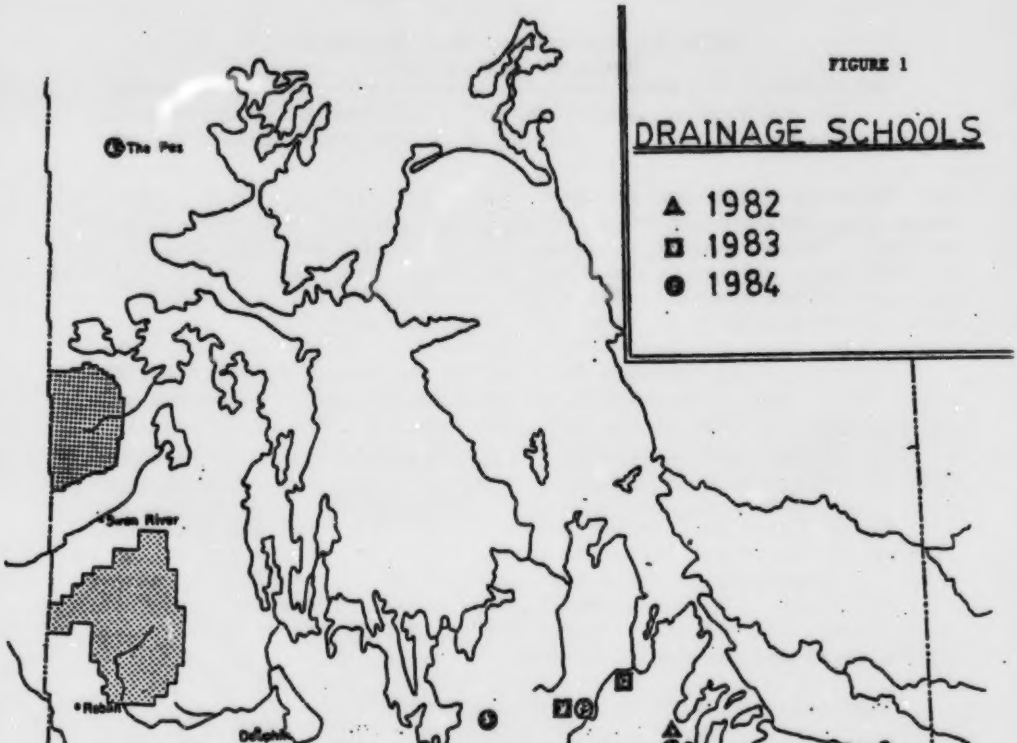

FIGURE 1

DRAINAGE SCHOOLS

▲ 1982
■ 1983
● 1984
The Pas
Swan River
Roblin
Dauphin
Minnedosa
Virden
Brandon
Assiniboine
Portage
Melita
Killarney
Carman
Morden
Winnipeg
Selkirk
Gimli
Steinbach
LAKE MANITOBA
LAKE WINNIPEG
SASKATCHEWAN
ONTARIO
UNITED STATES

Drainage School Schedule

Day 1	A.M. - Planning Surveys, Theory of Profile Levelling - Classroom
	P.M. - Testing the Level, (Peg Test) - Field Start Surveying Field
Day 2	A.M. - Continue Field Surveying - Field
	P.M. - Ditch Design - Classroom
Day 3	A.M. - Construction Practices, Quiz - Classroom
	P.M. - Ditch Construction - Field

The emphasis is on practical experience with the surveying instruments, with some simplification in light of the nature of the level of surveying taking place. A prime example of this is in the method used to determine ditch cuts directly from the ditch profile drawn up during the school. The metric system of measurement was used throughout the course, with some translation into Imperial units as required. Surveying instruments used were either the property of Manitoba Agriculture, or graciously loaned by local surveying equipment dealers. Those participants who successfully completed the quiz received certificates. An attempt has been made to provide a surveying instrument in those areas where a school has been held.

If weather conditions and other factors permit, the school culminates with the construction of the ditches surveyed and designed by the participants. This has happened in 50% of the schools run to date.

and Evaluation:

Refer to Table 1 for some of the relevant statistics associated with these schools.

Table 1

Impact of Drainage Schools*

	Participants In		
	1982	1983	1984
No. of Schools	4	4	10
No. of Participants	40	63	82
Percentage of Partipants:			
a) who have done surveying after course		70%	30%
b) who have improved ditches after course		85%	53%
c) who have done surveying and/or ditching for neighbours		23%	20%

	1982	1983	1984
projected number of quarter sections improved (cumulative)		164	30
no. of quarters improved - by active participant annually		2.8	0.7
satisfaction level - percentage rating course good to very good		90%	86%

*Based on telephone survey of 20% of 1983 and 1984 participants November 1984.

The fall of 1983 allowed ditch construction well into November. This fall (1984) was not a good year for this type of activity, consequently surveying and ditching were reduced in 1984. It is important to note that the effect of drainage schools is cumulative, as participants from previous schools continue to survey and improve their drains year to year. For example, for 1985, with no new schools and poor fall weather, a minimum level of surveying activity (like 1984) would see a projected 50 quarter sections improved. Alternately an extended fall could see up to 300 quarter sections improved.

Another point to consider in the evaluation is the cost-effectiveness of these drainage schools. Figures prepared by Neil MacAlpine reveal that for the cost of a single drainage school, Manitoba Agriculture can have seven quarter sections surveyed by the summer student surveying service. Schools have averaged between 8 and 10 participants, so the likelihood of more than seven quarter sections being surveyed as a result of a drainage school could be easily achieved. In addition, the timeliness of the farmer being able to do the surveying when he wants to is difficult to put a dollar value on.

The limitations of direct service through summer students has forced Manitoba Agriculture to go to extension education to have a larger impact in assisting farmers with their drainage problems. Experience in the past three years has shown that the short course concept is cost-effective and can significantly influence drainage activities. The short course concept also has potential to deal with other farm water management issues. It has a high acceptance rate with farmers because it is an applied and practical solution to a real life problem.

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CROP RESIDUE MANAGEMENT IN CONSERVATION TILLAGE SYSTEMS

LYLE SAMSON
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My presentation will build around the experiences of conservation tillage farmers who have made residue utilization an intergal part of their crop production systems. I also want to share thoughts with you on the "why" of residue management and conservation tillage.

In developing methods that use, and still maintain a resource, it is helpful to look back at the ecological systems that developed it. Since my topic is plant residue, I ask you to reflect with me on the role of a plant in a natural setting. A seed germinates, and a new plant emerges. It grows, matures, reproduces, and then stays on upright to provide shelter and protection to the next generation. Then it falls to the earth, but remains on the surface as protective mulch. Finally it degrades to recycle its nutrients to nourish succeeding life forms of the commmunity. The usefulness did not end when new seed was formed. There were still vital functions for the plant to perform.

It is likewise true with crop residue. After seed has been produced, the plant material can continue to provide benefits. If on the other hand, we destroy residue at harvest time, or shortly after, we forego usefulness the plant material would have provided. We also leave the soil bare and vulnerable to erosion until the next generation of plants makes sufficient growth to protect the land.

To compare our common tillage systems with the natural way of things, let's visualize a time line that shows the relationship of old and new plant material. Think first of a natural prairie system. Plant residues stay on the scene long after seed formation, and well into the time when new material is being produced. A protective cover consisting of old, new, and a mixture of both, is on the soil throughout the year.

Now for maximum contrast, let's visualize a fall plow system. Before plowing, we have the residue left after harvest. Immediately following the plow it's essentially gone. Looking down the time line, it's a long way to go before new material appears. We've created a gap foreign to the natural scheme of prairie ecology. In the Northern Plains the gap is an 8 month period where the soil is exposed to driving winds, rain, blowing snow, and rapid runoff from snow melt.

The use of non-inversion tillage methods instead of the moldboard plow will retain some of the usefulness of the residue. The minimum till system endeavors to maintain residues after seeding to provide protection until new growth comes on. A no-till system most closely duplicates the natural cycles of old and new material. It is obviously the most effective in protecting soil from erosion. Conversely, the fall plow system is the most hazardous. So--------why is it used?

To answer the question, let me say first, certainly no farmer does things without reason -----and when he follows a tillage system that creates an erosion risk, it is not to deliberately damage his land. No one intentionally does that!

So, what are the reasons for reduction -----and destruction-----of crop residues? Many. Too many to enumerate in the time I have, but let's list the big ones, and then go on to look at how some people are finding ways to work around the problems.

One of the principal reasons we bury residue is seedbed preparation. Our conventional drills are designed to work in a trash free, clean tilled, soft, mellow, fluffy soil. In the small grain regions we had few alternatives until the very recent development of no-till and minimum till drills that will seed small grain through crop residues.

Weed control to save soil moisture is another big reason for tillage and loss of residues, followed by disease and insect control, nitrogen tie up, and the need to spread residues to prevent interference with herbicides and fertilizer. We are making good progress in dealing with these problems. Our arsenal of herbicides is giving us weed control capabilities we could only dream about as recent as five years ago. Crop rotations can be designed to provide control for most diseases and insects. We believe the nitrogen tie-up associated with higher residue levels is a temporary problem. It appears once a minimum and/or no-till system is established, nitrogen releases catch up. As farmers become convinced of the need to spread residues back evenly, they are quite ingenious in devising ways to do it.

The no-tillers are the ultimate retainers of residue. It is interesting to note comments they make.

Luther Berntson has 6 years no-till experience on his northeastern North Dakota farm. Speaking about whether residues will break down when left on the surface, he said, "Where does a fence post rot? The part at the surface rots much faster than the part buried in the ground." He goes on to say, " This should tell us something about recycling crop residues. Most of us were brought up to believe we have to plow them down, but maybe that's not necessary." He also said he feels it is entirely possible when we bury residues, "we may be just putting disease spores in storage".

Jim McCutcheon of southern Manitoba is in his ninth year of zero-till. His farm is in the Red River Valley. The soils are predominately clay loam and loamy clay. When I first heard about his no-till I thought for sure those heavy soils would be like a parking lot in a few years-----but it hasn't happened. In fact, just the opposite is true. Organic matter is increasing, bulk density is more favorable, and the soils are soft and mellow, showing a very favorable tilth.

Bob Nowatzki is an agricultural scientist turned no-till farmer at Langdon, North Dakota. Talking about tillage, he said "Agriculture is not static. Farmers are quick to change in most areas---but they tend to stay very traditional in tillage. The modern tillage implements are really no different than what our grandfathers pulled behind the horses." On switching to conservation tillage from conventional systems, he said, "When you change systems, remember, any system will respond to management. Therefore the management must be for that system---and not a traditional management learned from another system."

Dean Hodson is a no-tiller from Ipswich, South Dakota. When he was asked why he's no-tilling, he said, with a sly smile on his face, "You have to change every once in a while to give the neighbors something to talk about." On a more serious note, he stated, "You've got to get your residue spread or you'll lose the game." his reply to the frequent question of whether soil become compacted in no-till was, "Our soil is actually getting softer on top. We have more organic matter----more bacteria."

Mark Bernstein, a young farmer on the North Dakota---Manitoba border, is in his third year of no-till. He lists four reasons for doing it. Soil conservation is first. His land lies on the foot hill slope of the Turtle Mountains, and is subject to severe water erosion. No-till is controlling the hazard. His other reasons are better moisture utilization, a chance to include winter wheat in his cropping options, and to improve the tilth of heavy clayey soils on his unit. He also comments on chaff management, saying you must spread it back where it came from. He devised his own spreader using strips of heavy belting to both throw and blow the material.

Nowatzki and Bernstein both commented on the potential conservation tillage has to reduce, and even eliminate summerfallow. Nowatzki said, "It seems to me that in the forty years we have to use our farms we should be able to raise more than twenty crops."

Jerry Presser of central North Dakota talks about the need to be open to try different techniques. He observed, "In a time of change, experience can be your worst enemy." Interesting thought, isn't it.

Dave Huckle farms in both North Dakota and Minnesota. Looking ahead to when his grandson inherits the farm, he said, "Someday when he farms, he may be seeding into standing stubble and someone will ask him why he does it that way-----and he'll reply, 'Well, that's the way my grandfather did'."

The Muggli Brothers of southwestern North Dakota are masters at maintaining stubble mulch on their summerfallow. They remodeled their blade cultivator until it would do what they thought it should. Some of the undercutters on the market today have features the Muggli's built into this machine. Tony Muggli says, "We don't till to till. We don't send the hired man out to till to keep him busy. We look the field over and consider weed growth, timeliness, how much residue we have, and how much we need to keep. All these factors are considered in a decision to till."

A most interesting and revealing study on the Muggli land was reported by Bauer and Black in their paper, "Soil Carbon, Nitrogen, and Bulk Density Comparison in two cropland Tillage Systems After 25 Years and in Virgin Grassland". (1) The two tillage systems compared were a crop and conventional clean tilled summerfallow rotation versus Muggli's crop and stubble mulch protected fallow. Comparisons were also made on relic grassland sites for reference condition indicators. Four field sites each of moderately coarse, medium, and fine textured soils were sampled for organic carbon, total nitrogen, and bulk density. Significantly higher levels of organic carbon and total nitrogen were found in fields under the stubble mulch system, particularily in the coarse and fine textured soils. The authors concluded that soil loss to erosion on the conventional clean tilled fields was the principle reason for the lower C & N levels.

And that brings me to my work---soil conservation. I would like to draw a parallel from range management to make a point. We use the term "condition" to indicate the relative well being of a range site in comparison to what it would be if it was still in a natural state. Along with a condition rating, the range manager seeks to discern the trend. He wants to know if the condition is remaining constant or is it improving, or is it degrading. If he concludes it's degrading, it obviously follows that management must be adjusted to reverse the trend.

The same concept can be applied to cropland. The management that has been used has caused the resource to be in a certain condition. So----what is the condition? And more importantly, what is the trend? Is the resource stable, and therefore being sustained----is it actually being improved----or is it degrading? If it's degrading, how fast is it occurring? What will be the effect? How much management change does it take to halt the deterioration? What type input, and how much is needed to turn the trend around? How far should we carry the trend of improvement? What reasonable "condition" level can we sustain?

In the real world we have every kind of condition and trend. Some of our soils are doing very well under cultivation----others are not. Let me take you on a forty one year journey with time lapse photography in one of our North Dakota counties.

SLIDE	NARRATIVE
1938	An aerial photo taken in 1938 of a quarter section of land in central North Dakota. The soils are medium textured loam developed from glacial till, and are on 6 to 9% slopes. It classifies as Class III land. The northeast forty acres tends to 9 to 12% slopes, and is Class IV. Small fields have grain in rows of shocks. There is no particular evidence of soil erosion.
1953 photo of same land	Fifteen years and one World War later the quarter section is now in three large fields. Note the color of the ridges-----they're beginning to show somewhat lighter than the swales.
1961 photo	Eight more years ahead in time brings us to 1961, a drought year. The wetlands are dry and being harvested for hay. The land is now farmed in one, or possibly two, fields. Notice the enlargement of the light colored areas on the knolls and ridges. The A horizon on knolls was not very deep to start with, but it is thinning in comparison to the previous years. A trend is at work-----and it's going the wrong way!
1969 photo	Another eight year jump. Concern for soil conservation has developed. The land has been stripcropped. The strips are not uniform, but they're there. It is commendable that a conservation effort is being made, but we wonder if the right medicine was used. Stripcropping is primarily a wind erosion control practice. I can easily believe water erosion is the principle problem.
1979 photo	A ten year jump. Shading differences have changed on knolls and swales. The lighter colored areas have greatly enlarged in the course of forty one years----------one generation! A dot counter used to measure the land area on photos shows the "A" horizon has been lost on over 50 acres. One-third of the cropland has very significantly lost productivity.
1984 on site scene	I wanted ground truth for the story the aerial photography was telling, so last May I drove out to the site and here's how the fields look today. Much of the surface is now "B" horizon, and some is even down to parent material.

1939 aerial photo	We ran the same time lapse comparison on a parcel of land in a western county. This shows the land in 1939. We'll be looking at a field approximately 50 acres in size, outlined by the dashed boundary. We see shock rows on part of the field. Note the knoll and ridge tops, and let's see if there's a trend in process.
1949 photo	Ten years later. The harvest method has switched from binder and shocks to swaths and combine. The knolls and ridges are beginning to lighten.
1958 photo	Nine years later we see the main field in summerfallow. There is evidence that soil on the upland is becoming thinner.
1966 photo	Eight years forward in this time lapse, and we find the field in summerfallow again. Loss of soil from the knolls and ridges is continuing.
1976 photo	This is 1976, ten years after our last picture, and thirty seven years after the first one. The trend is obvious. The condition of the field has deteriorated rather badly in this one generation time span.
Conventional tillage scene	The point of the time laspe journeys I took you on is to emphasize the tillage systems being applied to all too many our soils------
Scene of tillage scene	-------Are creating trends that are going the wrong way.
New land/old land scene	I call this my new land/old land picture. I took it a couple of years ago. I wanted to see what was over the hill, so I walked to the top, and this was the scene.
Second new land/old land scene	We see new breaking on the right side. There were still sod chunks in it. On the left, I'd estimate the field was broken out of sod in the late 1940's or 1950's. It is rather inescapable that the tillage system employed (and still used) created a trend that resulted in a significant degradation of the resource. It also follows the same is in store for the new land------unless management is changed.

Sid Ranson	Sid Ranson is a dedicated conservation tiller who farms on the Manitoba side of the Turtle Mountains. Some 30 years ago, he observed the loss of soil from the upper slopes of his fields, and resolved to turn the trend around. His first step was elimination of summerfallow since that's where most of the damage was occurring. He also devised cropping systems in which residues were maintained well into the next crop. He seeded with a drill called a "disker" until the minimum till and no-till drills came along. He has been controlling erosion and is restoring organic matter to his land.
Soil profile	This photo was taken on what had been an eroded upper slope on Sid's farm. In showing this site to a tour group, he made a statement that tells a great story about proper residue management. Pointing to the black organic matter zone on top, he asked the group to look at his "new soil". Then he said, "wouldn't it be a shame if someone plowed it down".

In closing, I'd like to make some observations on the conservation tillage effort. First, It's alive and well. We have a lot of reason to believe it will be equally profitable-----and could be more profitable than conventional systems.

Second, the application of conservation tillage has a remarkably good effect on the trend, and therefor on the condition of the soil resource.

Third, we need to bring Conservation tillage on. Think of all the soils that are on a trend of degradation. There is a point where profitability ends. Isn't it much better to adopt conservation tillage before that time arrives------than to be faced with land reclamation later.

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SOIL CONSERVATION - "A PRACTICAL VIEWPOINT"

ROBERT C. McNABB

JANUARY 10, 1985 - MANITOBA SOIL SCIENCE COMMITTEE

There has been considerable interest in soil degradation in Canada this past year, - witness the Senate Committee report entitled, "Soil at Risk".

My message to you today is simply: "Zero-Till stops soil degradation!"

I have had five years of successful experience with no-till on rolling Newdale clay loam soil at Minnedosa, Manitoba. Similar experiences have been shared amongst members of the Manitoba-North Dakota Zero Till Farmers' Association, some of which have ten years of practical experience in no-till small grain production in the Upper Great Plains.

Three significant factors have evolved from this experience with the zero-till system.

1. Wind and water erosion of soil are reduced dramatically.
2. Soil organic matter levels can be increased, especially on eroded soils.
3. Available moisture is used more efficiently allowing for a reduction in summerfallow acreage and less salinity.

Therefore, we have a system of crop production that not only maintains the productive capabilities of our soil resource but also has the ability to sustain that production.

Because of the significant benefits of no-till as evidenced by only ten to twelve years of limited practical experience, it is essential that those of you involved in soil science continue or commence studies and research geared to further evaluate the no-till system of crop production.

Some of the soil areas that we, as farmers, have identified as requiring more research include:

1. The effect of various types of drill openers on soil physical properties of the seedbed and seedling emergence. The need for development of recommendations for seed placement, soil coverage, depth of seeding, packing over or beside the seed, soil surface topography realizing there may be different answers for different soil types and moisture conditions.
2. Development of recommendations for fertilizer forms, rates and placement in the no-till systems considering:

a) With the lack of soil mixing, moisture close to the surface and an organic layer close to the surface, some nutrients may be less available for plants to effectively use them.

b) The possibility of a fertilizer management - weed competition interaction.

3. The requirements for research into the movement and fate of agricultural chemicals in surface and groundwater with major emphasis on groundwater quality. For example, some recent research indicates that with the increase in organic matter under no-till, soil microbial activity increases and thus hastens chemical decomposition.

4. Research into the possibility of insect shifts (harmful and helpful) and disease organisms that are associated with winter soil temperature remaining higher under no-till.

5. Research into changes in soil physical properties such as soil compaction.

6. Development of comparative studies on microbial and earthworm activity under no-till and conventional systems.

Those of you here today who influence the appropriation of funds for, and direction of, research activities would certainly be advancing the development of a soil conserving system of crop production by contributing to the answer of these research requirements.

The benefits of the no-till system are real and significant and the present lack of long term documented effects of this system on soil physical properties should not be used as a deterrent to promoting no-till.

The conventional system of crop production has resulted in producing a number of well documented soil problems.

The advantages of no-till are simply too great to be shrouded by perceived problems.

First hand experience of soil erosion was dramatically evident to each and every one of us in Manitoba during the spring of 1984. Shelterbelts, windbreaks, cover crops and grass barriers may offer some temporary erosion relief for a small area but only through zero-tillage can large scale soil problems be solved effectively and efficiently.

The Effect of Soil Erosion on Soil Productivity: Preliminary Findings of a Two-year Study.

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Soil erosion on the prairies is once more receiving attention. The recent Senate Standing Committee on Agriculture Report on Soil Degradation has brought the situation to the attention of the general public. In many parts of agricultural Manitoba, lower than average precipitation over the past two years, combined with less-than-soil-conserving farming practices, have caused spring dust storms reminiscent of times that many would rather forget.

Assessing the effect of soil erosion on soil productivity is not simple. Research conducted in the United States (Pierce et al, (1983) and Schertz (1983)). while perhaps providing general guidelines for Manitoban researchers, strongly indicates that erosion effects are modified not only by soil texture, but also by other properties of the solum, by cropping practices and, of course, by local climate. Occasional, isolated weather conditions, which can cause unusually severe erosional events, often have a more profound effect on soil productivity than can be estimated from a study of average climatic conditions.

MATERIALS AND METHODS

To compare within-site differences in crop yields under erosion conditions, it is necessary that the site should be level and the soil profile uniform. Since these conditions are seldom met in the field (an 'eroded' field often consists of dry, eroded knolls and moister depositional areas) it was decided to conduct a 'scalping' experiment. In this method, erosion is simulated by removing various portions of the Ah horizon.

Two experimental sites were established in May, 1983, one on a Reinland LVFS near Gladstone and the other on a Newdale CL (smooth phase) near Minnedosa. At both sites, the Ah horizon was about 20 cm thick.

The experiment was built on a randomized, complete block design; four levels of topsoil removal (0, 5, 10 and 20 cm) were replicated four times. Each soil removal treatment was split into three fertilizer treatments: a control, the recommended rate and a higher-than-recommended rate of fertilizer application. The objective was to see if extra fertilizer would have a mitigating effect where topsoil had been removed. Sites were seeded to Benito wheat at 100 kg/ha in late May.

In 1984, the two first-year sites were again seeded to Benito wheat, as well as a newly-established third site on a degraded Pembina CL soil near Altamont. This year, 90 kg/ha N was included at all sites, in the highest fertilizer rate (Table 1).

Table 1. Fertilizer Rates and Seeding Dates.

	Seeding Date	Fertilizer Treatment		
		A	B	C
Reinland LVFS	1983 May 21	0	20 kg/ha P_2O_5	45 kg/ha P_2O_5 30 kg/ha K_2O
	1984 May 10	0	10 kg/ha P_2O_5	90 kg/ha N 45 kg/ha P_2O_5
Newdale CL	1983 May 27	0	20 kg/ha P_2O_5	45 kg/ha P_2O_5
	1984 May 9	0	35 kg/ha P_2O_5	90 kg/ha N 45 kg/ha P_2O_5
Pembina CL	1984 May 11	15 kg/ha S	40 kg/ha N 10 kg/ha P_2O_5 15 kg/ha S	90 kg/ha N 45 kg/ha P_2O_5 30 kg/ha S

Data collected during the two growing seasons included soil temperature, soil moisture and precipitation. Midseason tissue samples were taken when the crop was headed and final grain samples were harvested from each subplot at crop maturity.

RESULTS

Wheat Yields a) 1983. On the Newdale CL there was a consistent decline in yield with each increase in the amount of topsoil removed, while on the Reinland LVFS , only the 20 cm soil removal treatment had a substantially lower yield. At both sites, only the 20 cm soil removal treatment had a significantly lower yield than the control.

b) 1984. Average wheat yields on the Reinland LVFS soil decreased with each increase in topsoil removal. Where 10 or 20 cm of topsoil had been removed, yields were significantly lower than the control. This year, this trend was not seen on the Newdale CL. There were no significant differences among wheat yields where 5, 10 or 20 cm of topsoil was removed, although these were significantly lower than the average wheat yields obtained from control plots at P=0.1. On the Pembina CL soil, wheat yields between control plots and those where 5 or 10 cm of topsoil had been scalped were not significantly different, but average wheat yields from the deeply scraped plots (20 cm) were significantly depressed when compared to controls. (Table 2).

Table 2. Wheat Yield.

		Wheat Yield (tonnes/ha)*	
Site	Depth of Topsoil Removed	1983	1984
Reinland LVFS	0	1.603a	2.297a
	5	1.708a	1.911ab
	10	1.389a	1.551bc
	20	0.575b	1.073c
Newdale CL	0	2.768a	2.785a
	5	2.231a	2.306a
	10	2.040a	2.269a
	20	1.633b	2.263a
Pembina CL	0		2.986a
	5		3.043a
	10		2.876a
	20		1.498b

* Within location and year, means followed by the same letter are not significantly different at P = 0.05.

Effect of Fertilizer In the first year of this study, fertility treatments had no significant effect on yield at either site. On the LVFS, subplots that were fertilized to soil test recommendations yielded slightly less than those which received either no fertilizer, or the heavier fetilizer application. On the Newdale CL, the soil test recommendation treatment had the highest yield with the other two treatments slightly lower. In 1984, however, significant fertilizer effects were seen. At all three locations, grain yields (averaged over soil removal treatments) were significantly higher in the subplots that had received the heaviest fertilizer application (Table 3).

Crop Germination In 1983, wheat germination was uneven on the scraped plots of the Newdale soil. Although no significant germination differences were found at any of the sites in 1984, 'scalped' plots on the Newdale CL showed signs of tractor tire compaction well into the season, and in these places, crop growth was somewhat slow.

Table 3. Effect of Fertilizer Treatment on Grain Yield.

Site	Fertilizer Treatment	Grain Yield (tonnes/ha)* 1983	1984
Reinland LVFS	A	1.356a	1.481a
	B	1.253a	1.571a
	C	1.347a	2.072b
Newdale CL	A	2.065a	2.172a
	B	2.353a	2.231a
	C	2.087a	2.814b
Pembina CL	A		2.148a
	B		2.363a
	C		3.291b

* Within location and year, means followed by the same letter are not significantly different at $P = 0.05$.

Growing Season Precipitation During both years of this study, growing season precipitation was below the long-term average for each area. Analysis of soil moisture data is not yet complete: some researchers (Frye et al. (1982)) have suggested that a decrease in available water-holding capacity was the most important yield-limiting effect in the eroded soils they investigated.

DISCUSSION

When topsoil is lost to erosion, soil organic matter is also lost. At all three field sites, in the top 15 cm of soil, the organic matter content of the most deeply scraped plots was less than fifty per cent of that found in the controls (Table 4). Since soil organic matter (by aiding aggregation and providing ground cover) helps protect soil from erosion, the decreased organic matter content of eroded soils can leave them more vulnerable to further erosion. On the loamy sand site, wheat yields on some of the 20 cm plots were so low that crop residues would be insufficient to protect this soil into the next crop year.

Table 4. Soil Organic Matter Content, Late Fall, 1984.

Depth of Topsoil Removed	Per cent Organic Matter in the Top 15 cm of Soil Reinland LVFS	Newdale CL	Pembina CL
0	2.5	6.7	2.9
5	1.7	3.0	2.3
10	1.5	3.4	1.8
20	1.1	3.3	1.0

It is worthwhile to note that, in 1984, at all sites, while fertilizer response was not always uniform in the control and 5 cm plots, on the 10 and 20 cm soil removal plots, the highest fertilizer application increased grain yields substantially. It is also noticeable that, in all cases, the highest yields achieved on the 10 and 20 cm subplots did not equal the highest yields obtained from the control subplots (Table 5).

Table 5. Highest Grain Yields Obtained in 1984.

Site	Depth of Topsoil Removed	Fertilizer Treatment	Yield (tonne/ha)
Reinland LVFS	0	A	2.35
	5	C	2.05
	10	C	1.99
	20	C	1.95
Newdale CL	0	C	3.13
	5	C	2.58
	10	C	2.66
	20	C	2.89
Pembina CL	0	C	3.81
	5	B	3.20
	10	C	3.67
	20	C	2.55

This year, extra fertilizer improved yields on the more deeply 'scalped' plots, but not, it seems, to the original level of soil productivity. In 1983, wheat yields on the 10 and 20 cm plots remained low, despite extra fertilizer inputs.

Many site-years' data would be needed to fully evaluate the effect of soil erosion on a soil's productivity. Preliminary results of the present study indicate that soil erosion reduces crop yields, that extra inputs can often improve the productivity of eroded soils, and that, dependant on soil characteristics and management practices, the original (uneroded) productivity of the soil may not be completely regained.

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SIZE DISTRIBUTION AND STABILITY OF DRY SURFACE SOIL AGGREGATES AND THEIR EFFECT ON WIND EROSION POTENTIAL IN WESTBOURNE, R.M.

M. N. Langman

Over 30 years of wind erosion research in the United States (Chepil 1950, 1954,1956; Armhurst et. al. 1964; Woodruff and Siddoway, 1965) has established a strong relationship between the proportion of dry soil aggregates at the ground surface less than 0.84 mm in diameter and the potential of soils to erode by wind. This research also showed that the relative resistance of soil aggregates to breakdown can influence erosion potential. Aggregate stability (resistance to breakdown) was found to vary directly with resistance of the soil aggregates to abrasion and movement by wind - blown soil material. Aggregate size and stability, and hence wind erodibility, varies from season to season and virtually from day to day, depending on local weather conditions, tillage practises and the nature of the soil (Chepil, 1950). Therefore, it is essential to evaluate these soil aggregate factors during the season when the erosion hazard is most significant.

The objectives of this study were:

1. To measure the size distribution and relative mechanical stability of soil aggregates found at the ground surface in Westbourne, R.M. during the "critical" wind erosion month of May (Slevinsky, 1980).
2. To evaluate the change in aggregate size distribution and relative mechanical stability of soils after common spring tillage practises, and the resultant effect on wind erosion potential.

METHODOLOGY

Field Methodology: Sixteen fields representing the major surface soil textures in Westbourne were selected for the study. Eight representative fields are presented in this paper (Figure 1). All samples were collected in the month of May. Fields were sampled prior to spring tillage and again after spring tillage and seeding was completed. Site 5 was summer fallowed. Fall tillage techniques included either two cultivations or one cultivator and one tandem disc operation. Spring tillage included one or two passes with a cultivator and seeding with a double disc press drill where applicable.

Most surface residue was removed by hand from two - 1 m^2 sample sites in each field. Approximately 2 kg of soil was scraped from each site to a depth of 2.5 cm using a flat-bottomed metal scoop. The two samples per field were combined and transported to the laboratory.

Laboratory Methodology: A 0.5 kg subsample of the bulk field sample was analyzed for particle size analysis organic carbon, pH and $CaCO_3$ equivalence using standard methods. The remainder of each sample was spread on trays to air dry for 48 hours.

After drying, each weighed and dried aggregate sample was analyzed using a rotary sieve (Chepil, 1962). The sieve separated each soil sample into seven size fractions (>38.5, 38-20, 20-6.5, 6.5-2.3, 2.3-1.0, 1.0-0.84, <0.84 mm).

The sample separates were weighed and then recombined after sieving. Sieving and weighing of the separates was repeated a total of three times to estimate the relative resistance of the soil to breakdown by mechanical forces such as tillage or abrasion by wind erosion. This is called mechanical stability (Chepil, 1962). The size distribution and mechanical stability of the aggregates were thus determined simultaneously.

RESULTS AND DISUCSSION

It should be noted that all study fields showed signs of erosion damage prior to spring tillage. Some of the coarser textured soils displayed the effects of significant soil movement and deposition in ditches and along wind breaks. Also the sampling and sieving procedures caused some aggregate breakdown. Therefore the percentage of in situ aggregates would be somewhat higher than the laboratory measured amounts.

Dry Aggregate Size Distribution: Table 1 summarizes the physical and chemical properties of the surface soils in each study field. These representative soils ranged from non-calcareous fine sands which classify as potentially extremely wind erodible (Soil Conservation Service, 1975), to calcareous clay loams which classify as moderately to highly erodible.

Table 2 summarizes the dry aggregate size distribution of the surface soils sampled before and after spring tillage. This table also shows the effect of repeated sieving on the relative mechanical stability of the dry aggregates. The first sieving of each sample approximates the size distribution of surface aggregates originally present in the sampled fields.

Before spring tillage, over 80% of the dry aggregates for all soils were within the critical size range for wind erosion suseptibility (i.e. $<$0.84 mm). The soils with the highest percentage of potentially erosive aggregates were those with LVFS, VFSL and LFS surface textures. Previous work has shown that surface vegetative cover, surface roughness, wind barriers and surface soil moisture can alter this erosion potential (Woodruff and Siddoway, 1965).

After spring tillage, there was a decrease in the percentage of dry aggregates less than 0.84 mm in diameter for all soils. This decrease ranged from 3.3% for site 4 to 33% for site 3 after the first sieving. The soils with the largest decrease in less than 0.84 mm aggregates were those with CL surface textures. This became more apparent after the third sieving when CL textured soils exhibited a greater than 20% decrease in less than 0.84 mm aggregates while all other soils had a 10% or less decrease. These soils also had the lowest percentage of potentially erosive aggregates. Soils with the smallest decrease in less than 0.84 mm aggregates were those with very fine sand textures (i.e. LVFS, VFSL). These soils also had the largest percentage of erosion suseptible aggregates after spring tillage. The largest percentage of dry aggregates greater than 0.84 mm occurred in the 6.5-2.3 mm size range for all soils.

The decrease in potentially erosive aggregates suggests that the relative wind erosion suseptibility due to inherent soil erodibility decreased for all soils after spring tillage. Tillage probably increased surface roughness as well which can reduce suseptibility to wind erosion. This does not mean that the actual wind erosion on each field has been reduced.

The decrease in erosive potential due to increased aggregate size must be assessed against the effect of tillage on wind erosion controlling factors such as vegetative cover and soil moisture.

Table 3 shows the potential estimated annual soil loss from each field based on the percentage of dry aggregates greater than 0.84 mm in diameter. The estimated losses were derived from the data presented in Table 4. The soil loss figures are estimates of the most severe erosion that could occur on a field in Kansas and are presented here only to show the magnitude and relative effect of various percentages of erodible aggregates on annual soil loss. Before spring tillage estimates of potential loss from wind erosion ranged from 220 to 560 tonnes/ha/years. After tillage soil loss estimates ranged from 116 to 336 tonnes/ha/year. Spring tillage reduced erosion potential by approximately half for most soils examined with a maximum reduction of over 300 tonnes/ha/year for site 6.

Aggregate Stability: Figure 2 illustrates the relative stability of surface soil aggregates. These graphs show the weight-percentage of aggregates less than 0.84 mm in diameter after repeated sievings. The greater the slope of the curve, the lower is the mechanical stability of the soil aggregates.

The aggregates formed on CL textured soils (sites 2 and 3) after spring tillage were approximately as stable, or were more stable, than those found before spring tillage. Aggregates formed during spring tillage on VFSL (site 4), FSL (site 7) and FS (site 8) textured soils were slightly less stable than the aggregates present before spring tillage. Aggregates produced by spring tillage on LVFS (site 1), FS (site 5) and LFS (site 6) textured soils appeared much less mechanically stable than those found at these sites before spring tillage. Therefore, the moderately fine textured soils (site 2 and 3) produced relatively more stable dry aggregates after spring tillage than the coarser textured soils. The sandy loam textured soils (sites 4 and 7) showed little change in the mechanical stability of their surface aggregates after tillage. The coarse textured soils (site 1, 5 and 6), with the exception of site 8, had less stable aggregates after spring tillage. The relative stability of aggregates after tillage appeared to increase as clay content increased (Table 1) in all fields except site 8.

CONCLUSIONS

In the spring of 1984, all surface soils sampled for this investigation in the Rural Municipality of Westbourne were potentially moderately to extremely wind erodible as estimated by dry aggregate size distribution.

Spring tillage reduced the wind erosion potential of all wind erosive soils sampled in Westbourne. The relative mechanical stability of aggregates were reduced after spring tillage for all soils except those with CL textures.

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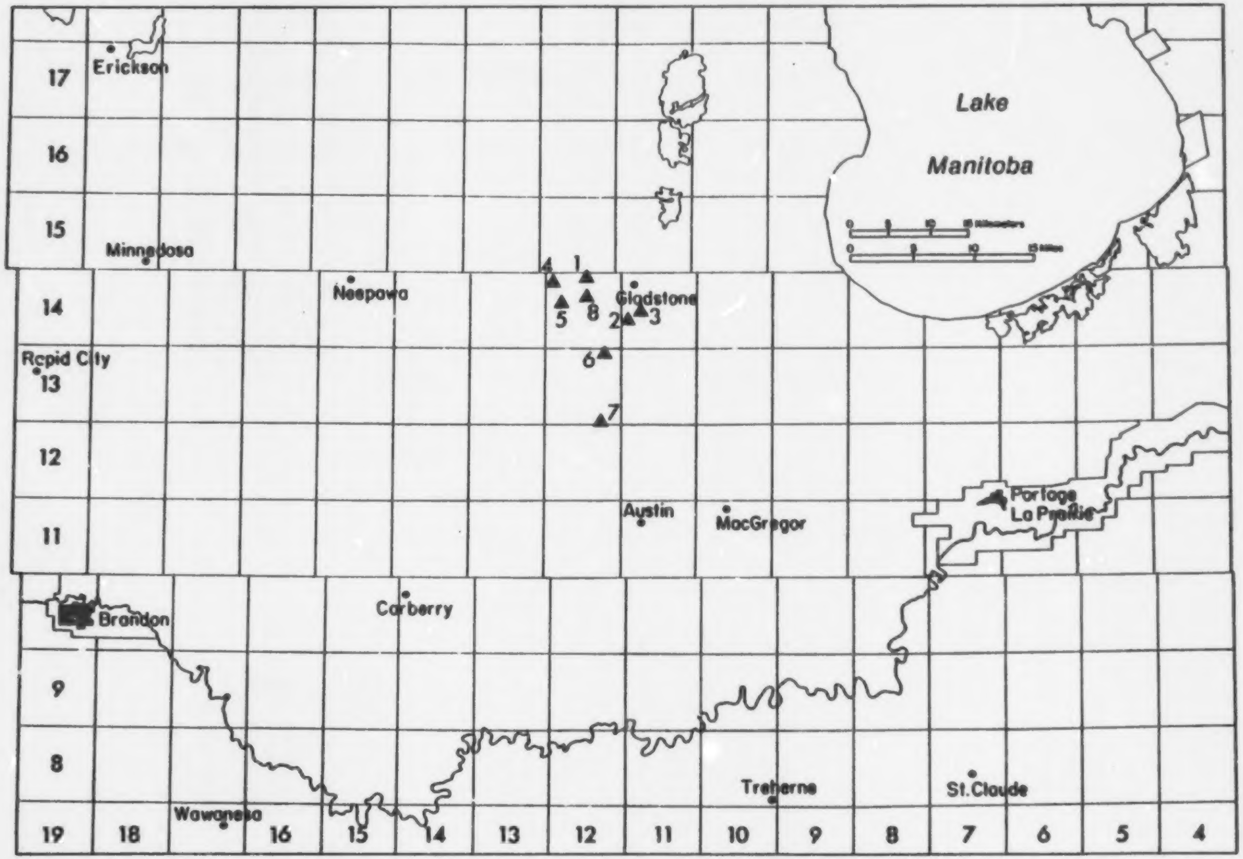
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Portage
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Figure 1. Location of the sample fields.

Figure 2. Effect of repeated sieving on the weight-percentage of aggregates <0.84 mm in diameter

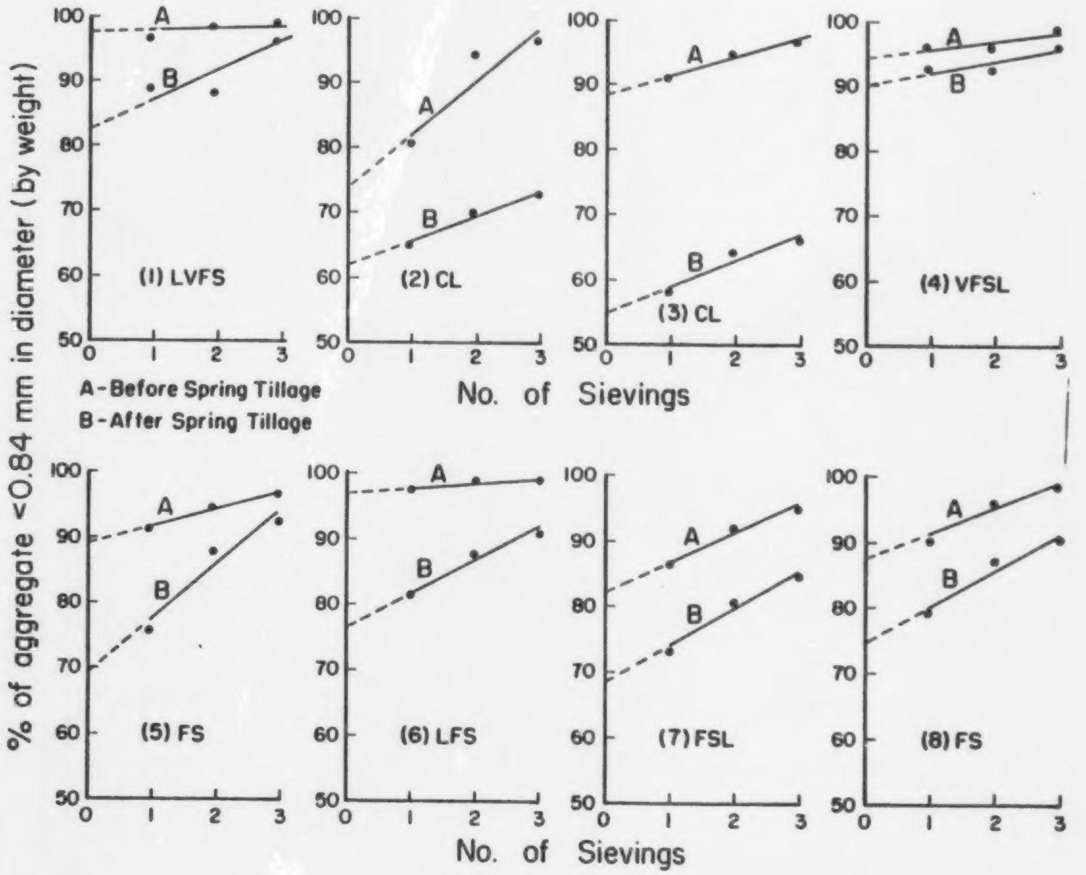

Table 1. Characteristics of surface soils sampled for dry aggregate analysis in Westbourne

Sample No.	Series Name	Particle Size Sand %	Silt %	Clay %	Textural Class	Organic Carbon %	pH	$CaCO_3$ Equivalent %
1	Reinland	85	6	9	LVFS	2.78	7.8	6.8
2	Gervais	30	37	33	CL	4.29	7.9	7.3
3	Gervais	31	30	39	CL	3.54	7.9	13.5
4	Reinland	71	10	19	VFSL	4.42	8.1	14.5
5	Long Plain	93	2	5	FS	1.18	7.3	0
6	Willowcrest	86	6	8	LFS	1.94	7.8	3.0
7	Almasippi	70	11	19	FSL	3.61	7.8	15.1
8	Long Plain	89	4	7	FS	1.70	7.5	4.5

LVFS - loamy very fine sand, CL - clay loam, VFSL - very fine sandy loam, FS - fine sand, LFS - loamy fine sand, FSL - fine sandy loam

Table 2. Size Distribution of Dry Aggregates After Repeated Sievings (distribution by percent weight)

Sample No. Texture	No. of Sievings	Before Spring Tillage Dry Aggregate Distribution							After Spring Tillage Dry Aggregate Distribution						
		38.5 %	38-20 %	20-6.5 %	6.5-2.3 %	2.3-1.0 %	1-0.84 %	<0.84mm %	38.5 %	38-20 %	20-6.5 %	6.5-2.3 %	2.3-1.0 %	1-0.84 %	<0.84mm %
(1)LVFS	1	0	0	0.3	1.4	0.7	0.3	97.3	0	2.7	2.1	6.5	1.6	0.3	88.9
	2	0	0	0.1	0.7	0.4	0.2	98.5	0.1	2.9	2.1	5.2	1.3	0.3	88.1
	3	0	0	0.1	0.6	0.4	0.2	98.6	0	0.7	1.1	0.4	1.2	0.3	96.2
(2)CL	1	0	6.6	4.8	5.9	2.0	0.5	80.2	0.9	8.2	5.9	13.6	5.9	1.4	65.0
	2	0	0.5	0.5	1.9	1.6	0.9	94.6	0.9	5.7	5.0	11.4	5.9	1.4	70.5
	3	0	0.2	0.3	1.3	1.3	0.4	96.5	0	4.4	4.7	10.7	5.8	1.4	73.0
(3)CL	1	0	1.8	0.7	2.6	3.0	0.7	91.0	8.3	11.0	5.0	11.6	9.8	5.1	58.0
	2	0	0	0.3	2.2	2.4	0.7	94.4	7.0	8.9	4.1	10.7	5.0	1.5	63.9
	3	0	0	0.2	1.1	1.7	0.7	96.3	6.1	7.7	3.9	9.8	5.0	1.6	65.9
(4)VFSL	1	0	0.9	0.7	2.2	0.5	0.2	95.4	0.3	0.8	1.5	4.3	0.7	0.2	92.1
	2	0	0.8	1.0	1.8	0.5	0.2	95.4	0	1.4	1.7	4.0	0.8	0.1	92.0
	3	0	0	0.3	1.0	0.5	0.1	98.0	0	0.1	0.8	2.5	0.5	0.1	95.6
(5)FS	1	0	1.2	1.8	4.4	0.8	0.4	91.3	1.4	6.2	5.4	9.1	1.8	0.3	75.8
	2	0	0.9	1.2	2.8	0.5	0.1	94.6	0	3.1	2.6	5.1	1.2	0.3	87.7
	3	0	0.2	0.6	1.8	0.6	0.2	96.6	0	1.4	1.5	3.5	1.0	0.3	92.3
(6)LFS	1	0	0.1	0.3	1.3	0.4	0.2	97.8	0	1.9	4.8	9.3	2.0	0.4	81.5
	2	0	0	0.1	0.6	0.3	0.2	98.8	0	1.1	2.5	6.6	2.7	0.3	87.7
	3	0	0	0.1	0.6	0.3	0.2	99.0	0	0.6	1.9	5.1	1.5	0.3	90.6
(7)FSL	1	0	4.0	2.5	5.1	1.7	0.4	86.3	0.1	4.7	5.7	13.2	3.4	0.6	73.1
	2	0	1.9	1.5	3.0	1.3	0.4	91.9	0	2.2	4.3	9.6	2.8	0.6	80.5
	3	0	1.1	1.0	2.3	1.1	0.4	94.9	0	1.6	3.2	7.8	2.4	0.5	84.5
(8)FS	1	0	1.9	1.9	4.5	1.2	0.3	90.2	0.1	5.5	4.3	8.3	1.8	0.4	78.0
	2	0	0.3	0.8	2.0	0.8	0.3	95.7	0	3.0	2.9	5.4	1.4	0.3	86.9
	3	0	0.1	0.5	1.4	0.7	0.3	98.2	0	2.3	2.0	4.0	1.1	0.3	90.3

Table 3. Comparison of the relative erosive potential of dry soil aggregates before spring tillage and after spring tillage.

Sample No.	No. of Sievings	Before Spring Tillage			After Spring Tillage		
		Dry Aggregates >0.84mm	Estimated Potential Wind Erosion*		Dry Aggregates >0.84mm	Estimated Potential Wind Erosion*	
		%	t/ac/yr	t/ha/yr	%	t/ac/yr	t/ha/yr
1	1	2.7	220	493	11.1	131	293
	2	1.5	250	560	11.9	128	287
	3	1.4	310	694	3.8	195	437
2	1	19.8	98	220	35.0	65	145
	2	5.4	180	403	29.5	74	165
	3	3.5	195	437	27.0	81	181
3	1	9.0	140	313	42.0	52	116
	2	5.6	170	380	36.1	63	141
	3	3.7	195	437	34.1	67	150
4	1	4.6	180	403	7.9	150	336
	2	4.6	180	403	8.0	150	336
	3	2.0	250	560	4.4	195	436
5	1	8.7	140	313	24.2	88	197
	2	5.4	180	403	12.3	128	287
	3	3.4	220	493	7.7	150	336
6	1	2.2	250	560	18.5	113	253
	2	1.2	310	694	12.3	128	287
	3	1.0	310	694	9.4	140	313
7	1	13.7	121	271	26.9	81	181
	2	8.1	150	336	19.5	98	220
	3	5.1	150	336	15.5	113	253
8	1	9.8	134	300	21.0	95	213
	2	4.3	180	403	13.1	125	280
	3	1.8	250	560	9.7	134	300

* average annual soil loss per acre that would occur from an "isolated", "level", "smooth", "unsheltered", "wide", and "bare" field with a non-crusted surface at Garden City, Kansas. (U.S.D.A. Soil Conservation Service, Bismark, N.D., 1975)

TABLE 4 - Soil Erodibility (average annual soil loss per acre that would occur from an "isolated", "level", "smooth", "unsheltered", "wide", and "bare" field with a non-crusted surface at Garden City, Kansas) for soils with different percentages of non-erodible fractions as determined by standard dry sieving.

Percentage of dry soil fractions > 0.84 mm. Units → Tens ↓	0	1	2	3	4	5	6	7	8	9
	T/A	T/A	T/A	T/A	T/A	T/A	T/A	T/A	T/A	T/A
0	-	310	250	220	195	180	170	160	150	140
10	134	131	128	125	121	117	113	109	106	102
20	98	95	92	90	88	86	83	81	79	76
30	74	72	71	69	67	65	63	62	60	58
40	56	54	52	51	50	48	47	45	43	41
50	38	36	33	31	29	27	25	24	23	22
60	21	20	19	18	17	16	16	15	14	13
70	12	11	10	8	7	6	4	3	3	2
80	2	-	-	-	-	-	-	-	-	-

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INTER-CROP SEEDING OF FALL RYE FOR CONTROL OF SOIL EROSION ON ROW-CROP LAND - THE P.E.I. AND MANITOBA EXPERIENCE

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Introduction

In the Maritimes and Manitoba, soil erosion is a serious problem, particularly on land used for row crops such as potatoes and silage corn. These crops leave little plant residue to protect the soil from erosion during winter and early spring when most of the erosion is likely to occur. In the Maritimes, erosion results from snow-melt and rainfall runoff. In Manitoba, wind erosion usually predominates.

Good control of this erosion could be achieved in theory by using fall-seeded cover crops. However, much of the potato hectarage and all of the corn hectarage are harvested too late in the fall for adequate establishment of a fall-seeded cover crop using conventional seeding techniques.

THE P.E.I. EXPERIENCE

Research was conducted at Charlottetown, P.E.I. to examine and develop a fall-seeded cover crop technique that would provide a practical, low cost method for the control of winter-spring soil erosion on row-crop land. All experiments were fully replicated (4 replicates per experiment) and were conducted on fine sandy loam Podzolic Grey Luvisols. Soil fertility levels were adjusted according to recommended P.E.I. fertilizer practices for fall rye based on soil test results.

1. Evaluation of Crop Species/Cultivars as Fall-Seeded Cover Crops

The first step was to establish which of the regionally-adapted crop species and cultivars were best suited for this purpose. The work was divided into a field study and growth chamber studies.

A. Field Study

Materials and Methods

Eight crop species or cultivars were seeded in 20-cm rows at recommended rates and depths in the fall of 1981 at each of 3 seeding dates - Sept. 9 and 16, which roughly correspond to the normal seeding dates for fall rye on P.E.I. (Sept. 1-21), and Oct. 2. There were 4 cultivars of fall rye plus Garry oats, Volla barley and 2 cultivars of what on P.E.I., is annual ryegrass (Table 1). Winter wheat was not included in the test since it must be seeded 2 weeks earlier than fall rye. Similarly, spring wheat cultivars generally are slower growing than oats or barley, while ryegrasses show greater early growth than other grasses adapted to the region. Aboveground plant material was sampled 4 days before the first killing frost (-3.0°C) on Nov. 26. Plant population and tillers/plant also were measured.

Results and Discussion

Above-ground fall growth of the fall rye cultivars was superior to that for all other crop species/cultivars tested for all 3 seeding dates except for Aroostook relative to oats and barley for the Sept. 9 and 16 seeding dates (Table 1). Differences in below-ground growth between the 8 crops followed the same pattern (data not shown). When the results in Table 1 were averaged over the 3 seeding dates, above-ground growth of Kodiak, which was the only one of the fall rye cultivars tested currently recommended for the Maritimes, was 75% greater than for oats or barley, and some 3.5 times greater than for either of the ryegrass cultivars. Relative differences in fall growth between fall rye, oats/barley, and ryegrass increased the later the crops were seeded.

Fall rye has additional advantages over the other crops as a fall-seeded cover crop due to its ability to survive winter:- 1) Fall rye will continue to grow in the fall after frosts have killed what are normally spring-seeded crops. 2) A living crop cover is more effective than the same quantity of dead plant material in controlling soil erosion. 3) Fall rye can be taken to maturity as a grain crop, thereby providing effective erosion control at no extra cost.

According to the regression equations in Table 2, seed size (K) accounted for 55, 63, and 81% of the difference in growth between the 8 crops seeded on Sept. 9, 16 and Oct. 2, respectively. These r^2 values increased to 79, 76, and 94%, respectively, when differences in tillering ability (Ti/P) were included in the equations.

B. Growth Chamber Studies

Following from the results of the field study, growth chamber studies were conducted on the fall growth characteristics of a range of fall rye or Secale Cereale cultivars grown under conditions of uniform plant population, and under a mild fall and a cold fall temperature regime for P.E.I. Only the cold fall results will be presented here since they should be more applicable to Manitoba fall temperature conditions.

Materials and Methods

There were 6 Secale cultivars- Kodiak, Tetra Petkus, Horton, Srebrne, Aroostook and a S. Cereale X S. Dalmaticum Polycross developed by L.F. Myers of C.S.I.R.O., Australia. They were grown on soil in 15-cm diameter by 15-cm deep pots. The pots were overseeded and thinned to 7 plants per pot after emergence. Sufficient pots were seeded to allow replicated destructive sampling for shoot and root growth at 14, 28, and 49 days after seeding. The plants were grown under a temperature regime that closely approximated actual temperature conditions likely to occur with a 5% probability at Charlottetown for the 7 week period starting Sept. 17. Weekly mean air temperatures declined from 12.2 to 5.3°C between week 1 and week 7 (Figure 1). Day length illumination, which was also changed weekly, declined from 12.2 h to 10.2 h.

Results and Discussion

Total dry matter production increased logarithmically with duration of growth (Figure 1). Kodiak produced significantly more total dry matter per plant than the other cultivars except at day 14, when Tetra Petkus growth marginally exceeded that of Kodiak. With this exception, the relative ranking in growth rate for the 6 cultivars was the same at all 3 sampling dates. By day 49, Kodiak had produced 29% more dry matter than Tetra Petkus, 55% more than Horton, 72% more than Srebrne, 98% more than Aroostook and 339% more than the Polycross.

Regression analysis showed that 99% of the variation in plant growth between the 6 cultivars at day 14 was due to differences in seed size (Table 3). For day 28 and 49, the r^2 values were 80 and 82%, respectively. At the latter 2 sampling dates inclusion of protein content and α amylase activity of the seeds increased these r^2 values to 91 and 87%, respectively. From these and similar results from the field study, it appears possible to select crop species and cultivars that have the greatest fall growth potential using readily determined seed and crop characteristics, most notably, seed size.

2. Inter-Crop Seeding a Winter Cover Crop for Erosion Control after Late-Season Harvested Row Crops

One way to overcome the problem of cover crop establishment after late-season harvested row crops, is to seed the cover crop before the row crop is harvested. This idea of inter-crop seeding (interseeding) is not exactly new, although its application for cover crop establishment for the control of winter-spring soil erosion after a row crop such as potatoes, the harvesting of which requires severe soil disturbance, is a new departure. Fall rye was chosen as the cover crop.

Materials and Methods

After the final application of chemical topkiller to the potato crop, Kodiak fall rye was broadcast interseeded at 160 $kg \cdot ha^{-1}$ (conventional recommended seeding rate is 130 $kg \cdot ha^{-1}$) on different areas of the potato crop. This was done at daily intervals from 4 to 10 days prior to mechanical harvesting the potatoes on Sept. 28, 1979, and on the same day after completion of the potato harvest. Rye stand counts were measured 4 weeks later on Oct. 25 to determine percent emergence and distribution of the plant population in relation to the original location of the potato hills. In the following spring, 40 $kg\ N \cdot ha^{-1}$ was applied broadcast to the fall rye and the crop combine harvested for grain yield in August.

Results and Discussion

Fall temperatures in 1979 were close to the 70-yr average (Table 5). Fall Rye seeded up to 6 days prior to the potato harvest showed better than 75% emergence and acceptable cover crop distribution across the potato hills (Table 4). It showed also a 1½ to 2 week advantage in rate of establishment and growth compared with rye seeded immediately after the potato harvest. Increasing the pre-potato harvest seeding interval to 7 or 8 days reduced rye emergence by 35%. Increasing the interval to 10 days reduced it by a further 24%. The seeding date effect on stand counts of the interseeded rye was related to the percentage of seeds that had germinated and made noticable shoot and root growth prior to the potato harvest. Where the rye was seeded more than 6 days before the potato harvest, more than 75% of the seeds had germinated, and more than 30% had developed to the stage where the shoots were at least 5 mm long and the roots were anchored in the soil. Plants in the latter category probably suffered high mortality due to wheel-track damage and soil disturbance by the potato harvesting equipment.

In general, the 2-fold difference in mean stand counts for the various rye seeding dates had little effect on final grain yield, due no doubt to the strong tillering ability of fall rye. Grain yields ranged from 3.0 to 3.5 $t \cdot ha^{-1}$ (Table 4). This compares fairly well with a yield of 4.6 $t \cdot ha^{-1}$ for an adjacent crop of Kodiak rye seeded conventionally the same year, particularly considering that the cost of interseeding would have been much less than for conventional seeding with all the attendant costs and time required for land preparation and drilling the seed.

It was concluded that broadcast interseeding fall rye in potatoes up to 6 days prior to the potato harvest should provide a timely, inexpensive, effective and practical method for establishing a fall-seeded cover crop for erosion control on P.E.I. Results from field-scale trials on P.E.I. farms confirmed these conclusions. From other work at Charlottetown, broadcast interseeding fall rye also appears to be a satisfactory method for establishing a winter cover crop for erosion control after silage corn and tobacco. However in the case of corn, problems will be encountered where there is heavy use of atrazine. Other work suggests that interseeding may be accomplished with equal facility if not cost by using ground broadcast equipment or aerial application.

THE MANITOBA EXPERIENCE

Success in adapting the interseeding technique developed for P.E.I. to Manitoba conditions depends on recognizing differences in fall growing conditions. Mean monthly air temperatures in Manitoba for Sept., Oct., and Nov. are 2.8, 4.0 and 8.6°C cooler, respectively, than for P.E.I. (Table 5). Thus, according to Manitoba recommendations, fall rye must be seeded at least a week earlier than on P.E.I. Also, in Manitoba, dry surface soil conditions resulting from lower rainfall amounts may delay germination of the fall rye. This may be beneficial for the interseeding technique since it may extend the interval between broadcast seeding the fall rye and the potato harvest without adversely affecting rye stand counts.

Field experiments were conducted to determine if fall aerial interseeding of fall rye in potatoes would provide adequate control of erosion under Manitoba conditions.

Materials and Methods

The experiments were set up in the Carberry area of Manitoba in cooperation with the Whitemud Watershed District and 3 producers, and were carried out by G. Shaw, Soil Management Specialist and M. Frank, Agricultural Representative at Carberry, both with Manitoba Agriculture. Fall rye was aerial seeded into commercial potato crops at 110 $kg \cdot ha^{-1}$ on Sept. 16, 1983 at three sites (total of 40 ha)- site 1 at NE 13-11-15, site 2 at SW 24-12-14 and site 3 at NW 7-11-12. The potato crops were harvested with commercial equipment on Sept. 19, 23 and Oct. 3, respectively. The soil was a Stockton fine sandy loam (wind erodibility group II). No fertilizer was applied to the fall rye. The crop was combine harvested at maturity by the producers in August, 1984.

Results

Fall rye at site 1 suffered serious winter kill and half the site was ripped up. Rye on the remaining half, despite the winter kill, still provided good protection of the soil from the severe wind erosion in the spring of 1984 and gave a grain yield of approximately 2.2 $t \cdot ha^{-1}$. Wet weather prevented discing after the potato harvest since the rye had germinated before it was possible to level the land. Site 2 was worked with a tandem disc immediately after the potato harvest. Even so, the rye still came up in rows but tillered out to give adequate control of soil erosion and a grain yield of approximately 2.5 $t \cdot ha^{-1}$. Despite the late potato harvest at site 3, weather conditions were favourable for rye establishment. Consequently, this cover crop gave adequate control of soil erosion and promised a grain yield of 2.0 to 2.5 $t \cdot ha^{-1}$. However, the rye suffered severe hail damage and was not harvested.

Discussion

Mean monthly air temperatures and rainfall for August through November in 1983 were close to the corresponding long-term averages (Table 5). The interseeded fall rye was in the 2 leaf stage by the time growth ceased in the fall even at site 3 where the potatoes were harvested on Oct. 2. However, earlier rye seeding and potato harvesting dates are suggested (ie. before Sept. 15) to ensure successful establishment and subsequent good winter survival of the rye in most years. Therefore, since the main crop potato harvest in Manitoba usually only starts in the second week of September and extends well into October, producers should select their most erosion-prone land for early harvest to permit use of cover crop technique for erosion control. Fields also should be disced once immediately after the potato harvest to anchor the potato tops and level the soil.

The interseeded rye emerged in strips with the largest proportion of the plants being in the bottom part of the furrow resulting from ridging by the potato harvester. Even so, the rye cover crop gave adequate control of the spring soil erosion at all sites since the adverse effects of uneven distribution of the cover crop was overcome by the strong tillering ability of this crop Also these rye crops produced grain yields that were only 0.1 to 0.2 $t \cdot ha^{-1}$ less than yields expected from rye seeded conventionally on this soil type. The cost of aerial seeding the rye was only $12 per ha. However seed costs ($10 per ha) were higher than for conventional seeding since the seeding rate for these interseeded experiments was 15% higher than the maximum recommended rate for Manitoba.

The results from this Manitoba work confirmed the conclusions from the P.E.I. research that interseeding a fall rye cover crop is a practical and cost-effective method for control of winter-spring soil erosion on early-harvested potato land.

Table 1

Effect of seeding date on above-ground growth rate per plant of various fall-seeded cover crops on P.E.I. in 1981[+]

Crop-cultivar	Seed size 1000 k wt	Plants/m^2	Above-ground growth rate Seeded Sept. 9	Seeded Sept. 16	Seeded Oct. 2
	g		-mg dry matter/plant/day		
fall rye					
- Tetra Petkus	46.8	63.4	6.11a*	3.17a	0.905a
- Kodiak	27.0	32.8	5.53a	2.25b	0.548b
- Horton	32.5	91.5	4.36b	2.22b	0.523b
- Aroostook	26.3	98.6	3.03c	1.92bc	0.469b
oats					
- Garry	31.1	67.6	3.17c	1.23d	0.296c
barley					
- Volla	42.5	53.2	3.06c	1.51cd	0.253c
annual ryegrass					
- Maris Ledger	4.9	74.1	1.66d	0.60e	0.079d
- Aubade	4.1	95.2	1.57d	0.58e	0.084d

[+] Plants sampled on Nov. 26, 1981; first killing frost - Nov. 30 (-3.0°C)

* Means for each column followed by the same letter are not significantly different at $P < 0.05$

Table 2

Effects of seed size and tillering on above-ground fall growth rates of eight crop species - cultivars seeded at three dates in fall of 1981

Seeding date	Regression equation	r^2
Sept. 9	$GR = 1.440 + 0.0789\ K$	54.60*
	$= -0.874 + 0.0754\ K + 0.491\ Ti/P$	79.05*
Sept. 16	$GR = 0.463 + 0.0454\ K$	63.44*
	$= -0.688 + 0.0429\ K + 0.355\ Ti/P$	75.95*
Oct. 2	$GR = -0.694 + 0.807\ Ti/P$	80.73**
	$= -0.659 + 0.634\ Ti/P + 0.00734\ K$	94.17**

Where GR = above ground growth rate (mg dry matter/plant/day).
K = 1000 kernel weight of seed (g).
and Ti/P = number of tillers/plant.
* $0.01 < P < 0.05$; ** $P < 0.01$

Table 3

Effects of seed characteristics on growth of 6 Secale Cereale cultivars grown in a growth chamber under a cold P.E.I. fall temperature regime

Days from seeding	Regression Equation	r^2
14	$GR = -0.0762 + 0.0611\ K$	.988***
28	$GR = 0.433 + 0.0709\ K$	.796*
	$GR = 0.0593 + 0.0670\ K + 0.000807\ AA$	.912*
49	$GR = 0.310 + 0.134\ K$	.820*
	$GR = -6.178 + 0.209\ K + 0.301\ \%P$	.871*

Where GR = tops + roots growth (mg dry matter/plant/day.
K = 1000 kernel weight of seed (g).
AA and %P = α amylase activity and % protein in seed, respectively.
* $0.01 < P < 0.05$; *** $P < 0.001$

Table 4

Effect of method and date of seeding fall rye in potatoes on P.E.I. on fall plant population and subsequent grain yield of rye

		Plant population on Oct. 25, 1979				
		Position on Potato Hill				
Method and date in Sept. of seeding	Approx % Germination by Sept. 27	Top 1/3rd	Mid 1/3rd	Bottom 1/3rd	Mean	1980 Grain Yield ($14\%\ H_2O$)
		------- plants.m^{-2}		-------		t.ha^{-1}
A) Broadcast interseeded prior to potato harvest+						
18	95	91cd*	125d	276b	164de	2.97b
19	90	69d	102d	279b	150e	3.16ab
20	80	189bc	214cd	393b	265cd	3.25ab
21	75	160bcd	199cd	350b	236de	3.48ab
22	10	213b	388ab	620a	406ab	3.02ab
23	0	232b	352ab	583a	389ab	3.16ab
24	0	195bc	302bc	598a	365bc	3.54a
B) Broadcast seeded immediately after potato harvest+						
28	0	453a	451a	560a	482a	2.94b

+ Potatoes mechanically harvested on Sept. 28: rye seeded at 160 kg.ha^{-1}.

* Means for each column followed by the same letter are not significantly different at $P < 0.05$.

Table 5

Fall weather conditions at Charlottetown, P.E.I. and Brandon, Manitoba

1) Mean Monthly Air Temperature (°C)

	Charlottetown			Brandon		
Month	1979		70-Yr	1983		94-Yr
	Mean	+/-	Avg	Mean	+/-	Avg
Aug.	17.5	3.4	18.5	21.4	8.5	17.3
Sept.	14.0	4.0	14.3	11.7	6.6	11.5
Oct.	9.0	3.0	8.9	5.1	7.0	4.9
Nov.	4.3	3.6	3.1	-2.2	3.3	-5.5

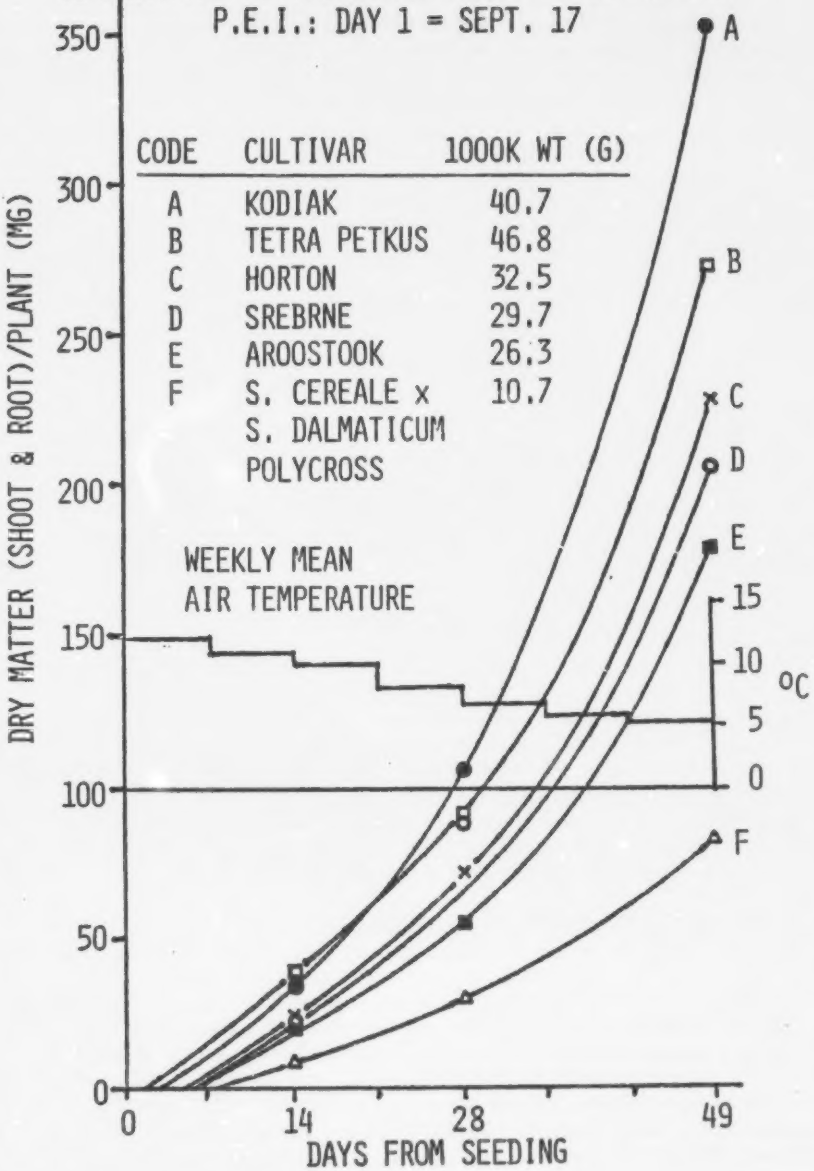
2) Monthly Precipitation (mm)

Month	1979	70-Yr Avg	1983	94-Yr Avg
Aug.	146	87	67	65
Sept.	110	94	41	47
Oct.	174	106	13	26
Nov.	146	105	17	21

3) First Killing Frost (< -2.0°C) in Fall

1979	Nov. 17	1983	Sept. 22
Earliest	Oct. 14	Earliest	Sept. 18
Latest	Dec. 5		

FIGURE 1. GROWTH OF SECALE CULTIVARS UNDER A TEMPERATURE REGIME SIMULATING A COLD FALL ON P.E.I.: DAY 1 = SEPT. 17



THE MODIFICATION OF GROUNDWATER SYSTEMS TO ENHANCE THE LAND BASE

L.R. Gray
Manitoba Department of Natural Resources

INTRODUCTION

Aquifer modification is a structural approach to water management. It involves putting in place engineering works that permanently modify the distribution of hydraulic head in an aquifer or an aquifer system. This modification results in changing the configuration of the water table in unconfined aquifers or the configuration of the potentiometric surface in confined aquifers. Aquifer modification is achieved by diverting water into or out of an aquifer or aquifer system.

In Manitoba aquifer modification is a relatively new water management tool being considered to resolve water related problems ranging from the control of icing in agricultural drainage systems to increasing the potable water supply capability of aquifers in water short areas. It has been utilized successfully to reduce winter ice build-up in the Netley Creek Watershed (Gray, 1984).

The purpose of this presentation is to provide some insight into the factors that contributed to the development of this water management tool.

GROUNDWATER ACTIVITIES

A basic pre-requisite to the adoption of aquifer modification as a water management tool is a knowledge and understanding of regional groundwater conditions. Since the early 1960's considerable resources have been allocated to obtaining a better understanding of Manitoba's groundwater resources. Support for this initiative has been provided by two cost-shared agreements between Canada and Manitoba. The Agricultural Rehabilitation and Development Act (ARDA) provided funding for regional groundwater investigations in Agro-Manitoba from 1964 to 1978 and the Interim Subsidiary Agreement on Water Development for Regional Economic Expansion and Drought Proofing (ISA) has provided similar funding since 1980.

Groundwater activities supported by ARDA served to develop a procedure for defining the regional groundwater framework in Manitoba. This resulted in the preparation of maps at a scale of 1:250,000 and associated cross-sections showing the regional geological framework and the associated groundwater conditions. The area of the province for which these maps have been produced are shown in Figure 1. In addition to regional mapping activities procedures for monitoring changes in groundwater levels and groundwater quality were also instigated. This resulted in the development of a network of observation stations instrumented to record changes in water levels and water quality. An illustration of regional groundwater conditions generated from the ARDA groundwater activities is indicated in the hydrogeologic cross-section (Figure 2) and the groundwater level fluctuations in the Interlake Region (Figure 3).

Groundwater activities undertaken under the ISA which began in 1980 resulted in some refinement in the methods used to define groundwater conditions in the province. The regional framework maps generated by the earlier activities enabled the selection of more precise groundwater map units for further investigation. The emphasis in groundwater activities changed from finding the resource to establishing the capability of the resource. Aquifer management units as shown in Figure 4 were selected as the basis for further investigations to define the water supply capability of the resource. This task requires a detailed knowledge of the flow pattern in each aquifer unit. The groundwater monitoring networks needed to establish flow patterns for the Assiniboine Delta Aquifer and the Oak Lake Aquifer are shown in Figure 5 and 6. Water level data from these networks will be used to construct models that will simulate the flow conditions in these aquifer units. This type of analysis provides not only an understanding of the groundwater conditions in the subsurface but also an understanding of the interface between water in the subsurface and water at the surface.

WATERSHED ACTIVITIES

The introduction of the Provincial Waterway system in 1966 as part of the land drainage strategy led to the establishment of 115 distinct watershed units in Agro-Manitoba. These watersheds form an excellent landscape unit in which the total water environment can be defined and evaluated. Figure 7 shows a representation of the groundwater resources in the Willowbend (Rat) Creek Watershed (Rutulis, 1981). In Figure 8 the disignated drains have been added to show the relationship between aquifer units and the surface drainage system. A typical watershed contains a highland area in its upper part near the drainage divide and a lowland area in the lower part of the watershed where the drainage system terminates. Each of these areas in the watershed generally exhibits distinct groundwater characteristics as outlined in Figure 9. By combining the groundwater system with the surface water system in a watershed unit we are able to appreciate some of the water management problems created by the interface of these two systems and to look for solutions to these problems.

AQUIFER MODIFICATION ACTIVITIES

Aquifer modification has been employed to resolve severe icing problems on agricultural drainage systems in two watersheds in the Lower Red River Valley identified in Figure 10 as Watershed No. 7 and Watershed No. 30. The surface drainage pattern for Watershed 30 which is typical for watershed units in the lake plain of the Red River Valley is shown in Figure 11. The drainage pattern is characterized by limited natural water course development in the lake plain portion of the watershed where extensive drainage works have been constructed using the right-of-way provided adjacent to each section of land. As the drainage works were being put in place numerous points of discharge developed where water from the confined aquifer underlying the watershed flowed into the drainage system on a continuous basis. The general configuration of the aquifer system underlying Watershed No. 30 is shown in Figure 12. The aquifer modification that resulted in reducing the icing problem in Watershed No. 30 consisted of reducing the pressure in the aquifer by increasing the discharge from the aquifer and limiting the number of points of discharge. This provided a concentrated flow of water entering the drainage system in a very localized area and resulted in normal under-ice flow in the portion of the drainage system receiving the discharge from the artesian aquifer. A similar aquifer modification has been implemented on Watershed No. 7.

Aquifer modification is also being considered as a solution to icing problems in watersheds where groundwater discharges into the drainage system from unconfined (water table) aquifers. Major unconfined aquifers associated with the Oak Lake Sand Plain and Assiniboine Delta are shown in Figure 13. A typical watershed unit where the interface between the surface drainage system and the underlying water table aquifer results in a severe icing problem is Watershed No. 38 shown in Figure 14. Here again the problem exists in that portion of the watershed where land drainage works have been developed. The hydrogeologic profile for Watershed No. 38 shown in Figure 15 provides an appreciation of the interface between the water table aquifer and the surface drainage system. The aquifer modification being considered to resolve the icing problem in Watershed No. 38 involves diverting water from the aquifer to lower the water table to a position below the base of the surface drainage system. Water diverted from the aquifer would likely be discharged into Pine Creek. Whether aquifer modification can be implemented as a solution to the icing problem in Watershed No. 38 will be determined by a feasibility study.

FUTURE AQUIFER MODIFICATION CONSIDERATIONS

Aquifer modification is a water management tool that has had limited application in Manitoba. Its application so far has been limited to resolving icing problems associated with land drainage works. The modification has resulted in the diversion of water from a groundwater system to a surface water system. Other types of aquifer modification could include the diversion of water from a surface water system to a groundwater system or from one part of a groundwater system to another part of a groundwater system.

In addition to the application of aquifer modification to enhance the agricultural land base it has potential for the enhancement of wetland habitat and water supply enhancement. Part of the water supply for the Oak Hammock Marsh is derived by diverting water from an artesian aquifer in the holding ponds. In terms of water supply enhancement an investigation is underway to establish the feasibility of diverting water from the La Salle River into a sand and gravel aquifer near Elie to increase the limited capacity of the aquifer.

Aquifer modification, like any other form of structural water management has an impact on the environment. It is therefore essential to ensure that the effects of each aquifer modification project be carefully evaluated to ensure that the positive benefits outweigh the negative benefits, e.g., The value of the increased agricultural capacity of the land exceeds the value of the decreased water supply capability of the aquifer.

REFERENCES

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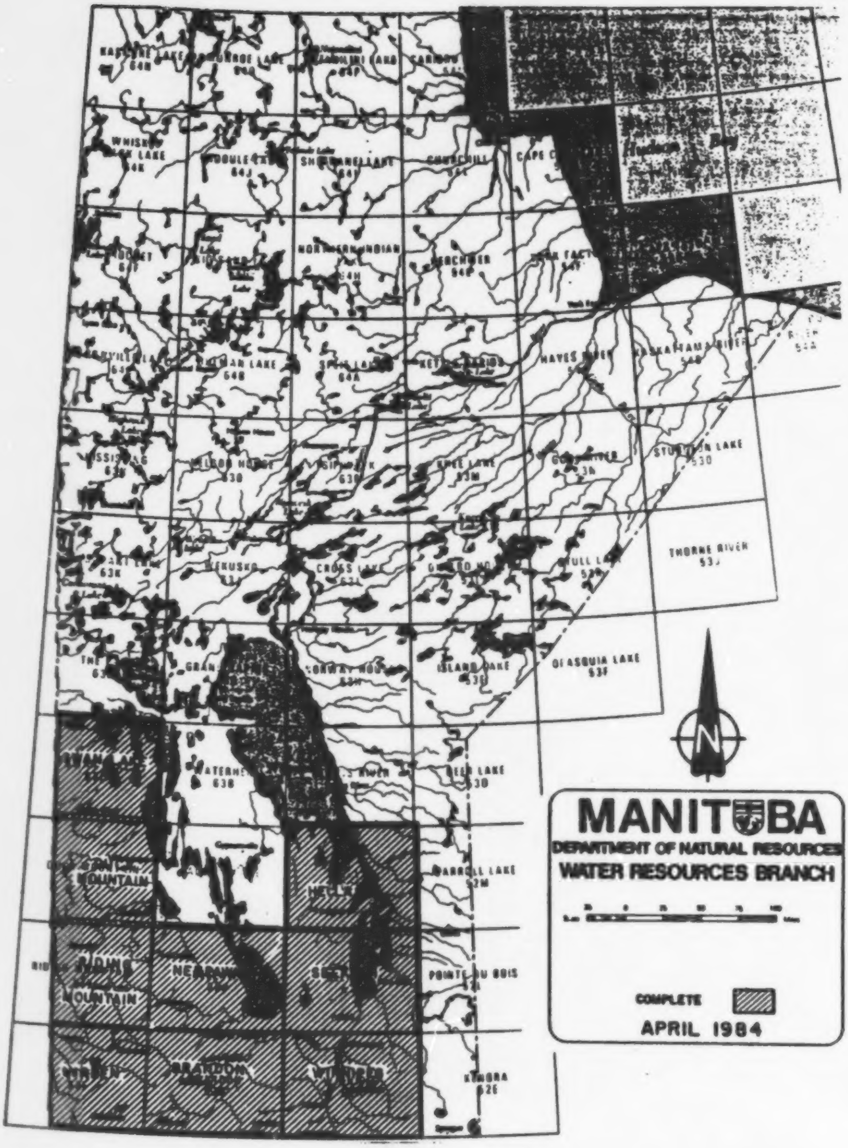
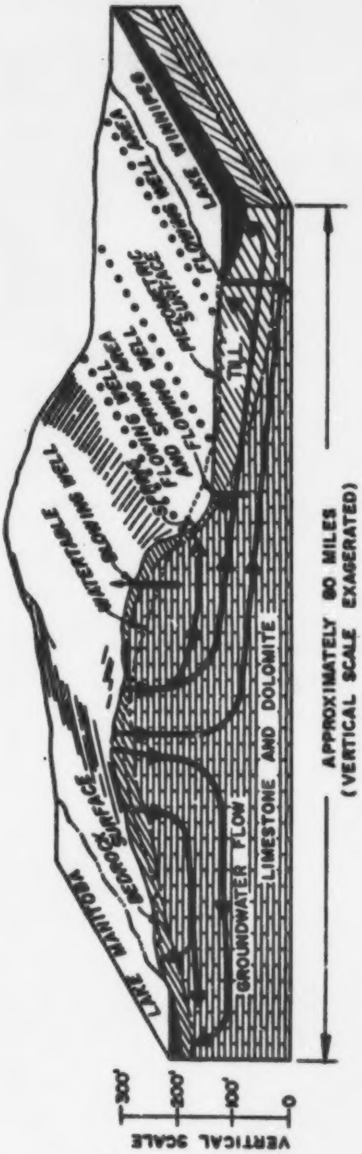
Rutulis, M. 1981. Groundwater Resources in the Willowbend (Rat) Creek Watershed. Manitoba Department of Natural Resources.


MANITOBA
DEPARTMENT OF NATURAL RESOURCES
WATER RESOURCES BRANCH
COMPLETE ▨
APRIL 1984
N
CHURCHILL 54L
NORTHERN INDIAN 64H
HAYES RIVER
KASKATTAMA RIVER 54B
STURGEON LAKE 53O
THORNE RIVER 53J
OLASQUIA LAKE 53F
ISLAND LAKE 53E
CROSS LAKE 63I
NORWAY HOUSE 63H
CARROLL LAKE 52M
POINTE DU BOIS
KENORA 52E
BRANDON
WINNIPEG
NEEPAWA
SELKIRK
RIDING MOUNTAIN
DUCK MOUNTAIN
Hudson Bay

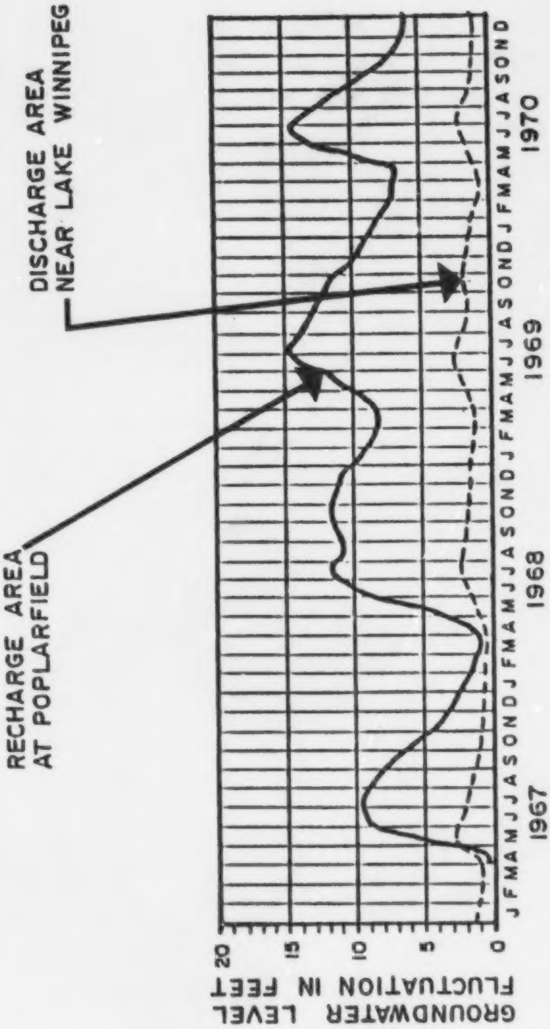
GROUNDWATER
AVAILABILITY MAPS

FIGURE 1


LAKE WINNIPEG
FLOWING WELL AREA
PIEZOMETRIC SURFACE
SPRING, FLOWING WELL AREA
FLOWING SPRING WELL
AND FLOWING WELL
TILL
FLOWING WELL
WATERTABLE
BEDROCK SURFACE
LAKE MANITOBA
GROUNDWATER FLOW
LIMESTONE AND DOLOMITE
APPROXIMATELY 80 MILES
(VERTICAL SCALE EXAGERATED)
VERTICAL SCALE
300'
200'
100'
0

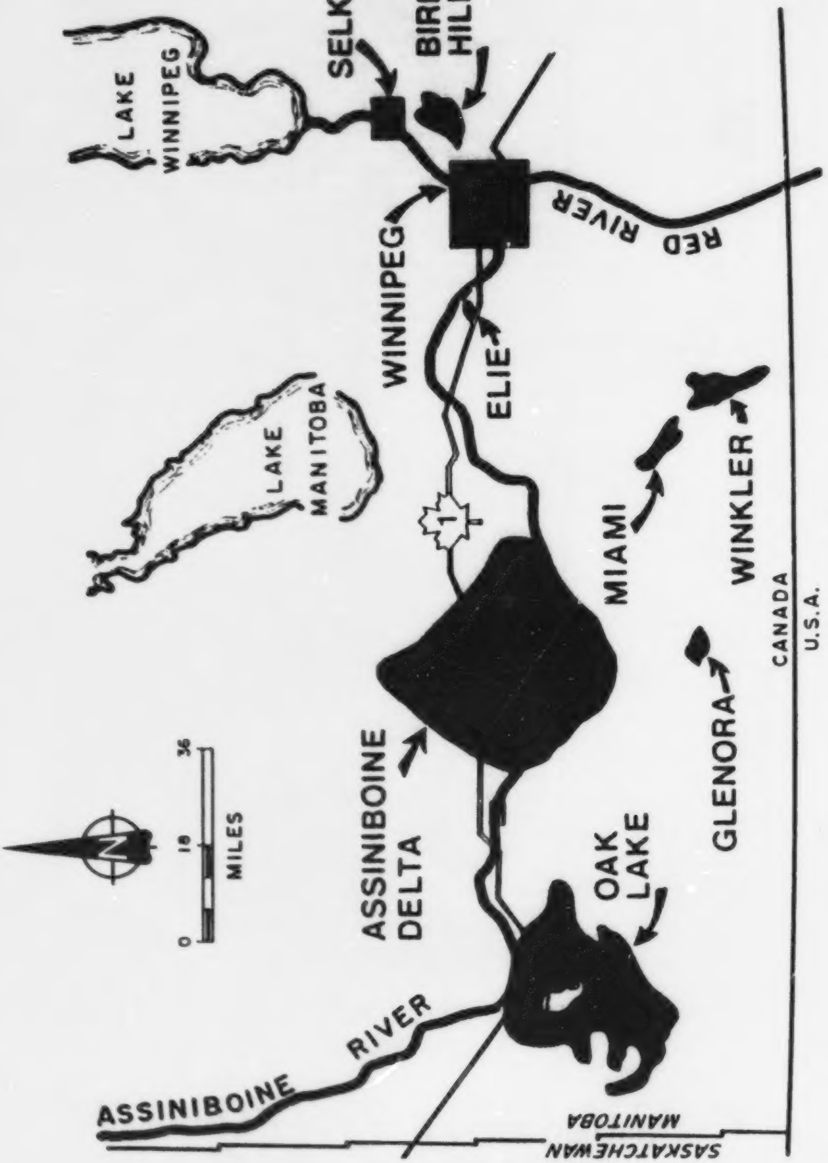
HYDROGEOLOGIC CROSS-SECTION
INTERLAKE REGION

FIGURE 2



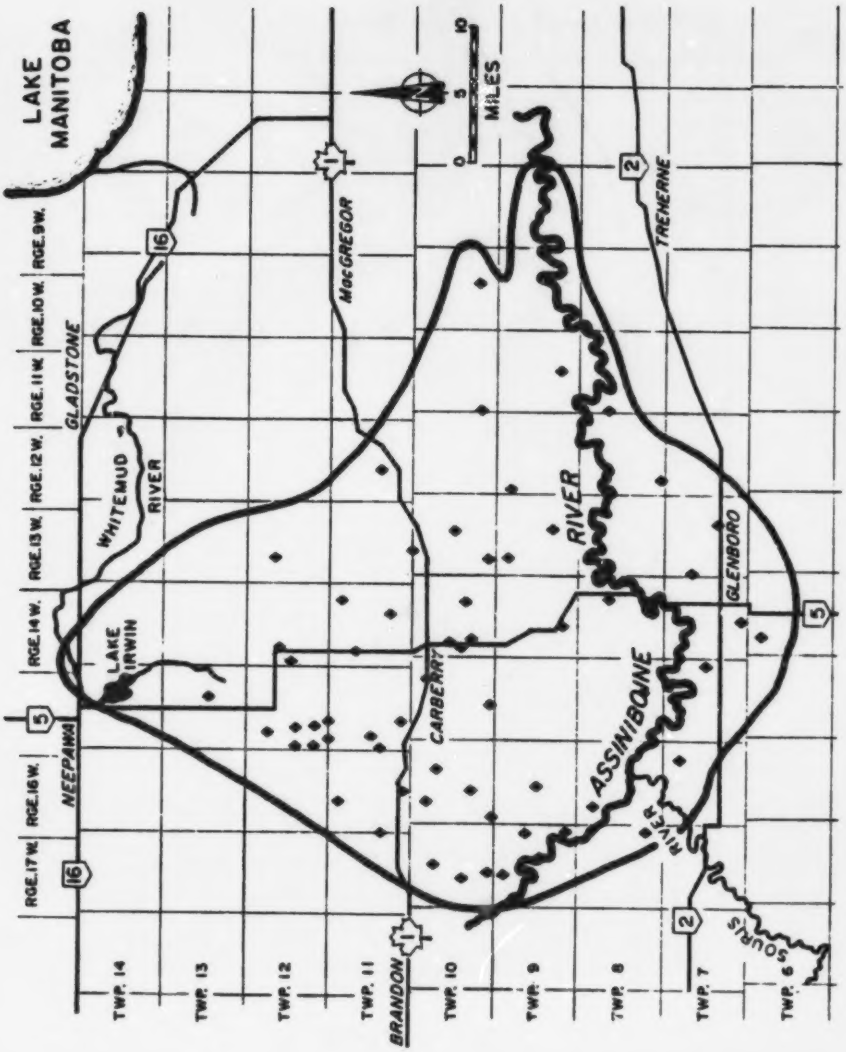
GROUNDWATER LEVELS
INTERLAKE REGION

FIGURE 3


LAKE WINNIPEG
SELKIRK
BIRDS HILL
WINNIPEG
RED RIVER
ELIE
LAKE MANITOBA
1
MIAMI
WINKLER
CANADA
U.S.A.
ASSINIBOINE DELTA
GLENORA
OAK LAKE
ASSINIBOINE RIVER
SASKATCHEWAN
MANITOBA
N
0
18
36
MILES

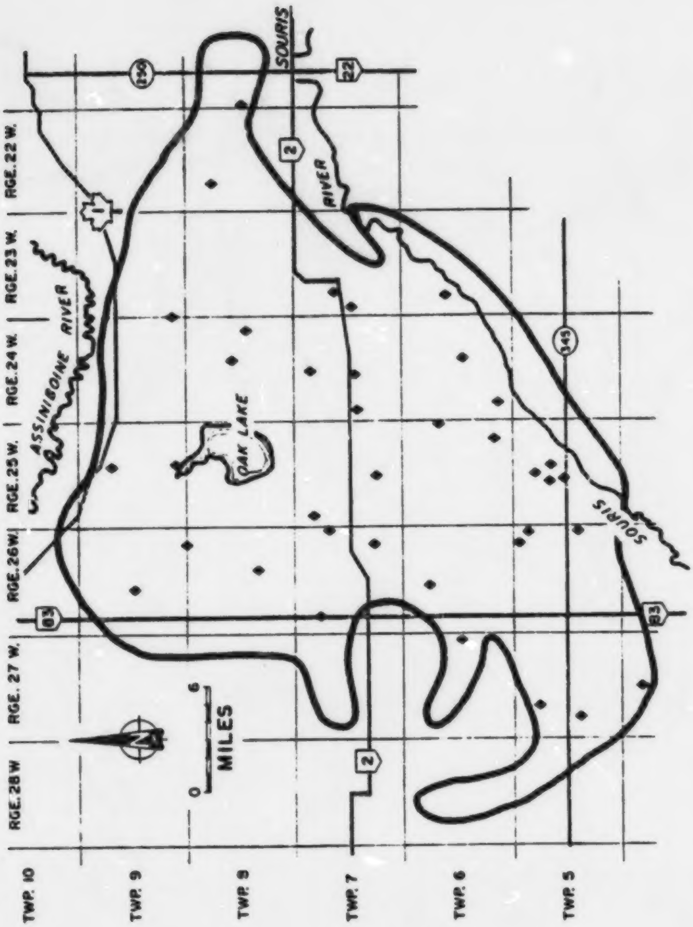
AQUIFER MANAGEMENT UNITS

FIGURE 4


LAKE MANITOBA
RGE.17 W.
RGE.16 W.
RGE.14 W.
RGE.13 W.
RGE.12 W.
RGE.11 W.
RGE.10 W.
RGE.9 W.
TWP. 14
TWP. 13
TWP. 12
TWP. 11
TWP. 10
TWP. 9
TWP. 8
TWP. 7
TWP. 6
NEEPAWA
GLADSTONE
MacGREGOR
TRENERNE
GLENBORO
CARBERRY
BRANDON
LAKE IRWIN
WHITEMUD RIVER
ASSINIBOINE RIVER
SOURIS RIVER
16
5
1
2
0
5
10
MILES
N

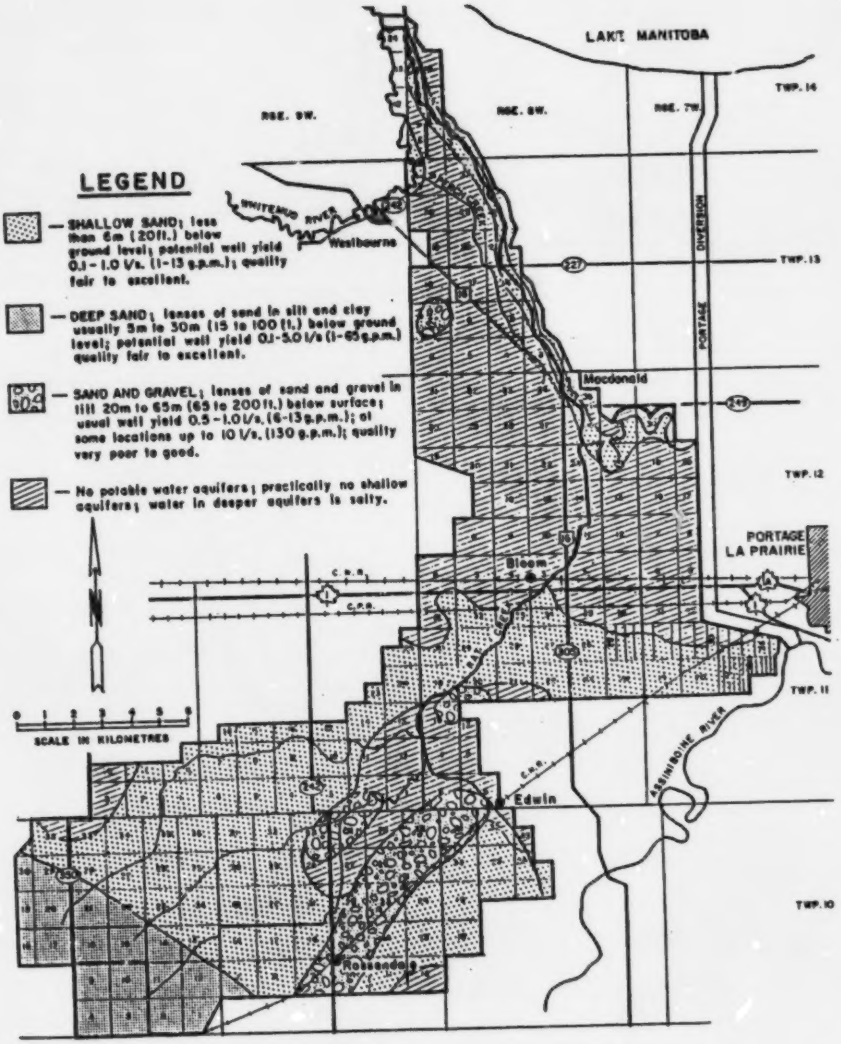
ASSINIBOINE DELTA
AQUIFER MONITORING STATION

FIGURE 5


RGE. 22 W.
RGE. 23 W.
RGE. 24 W.
RGE. 25 W.
RGE. 26 W.
RGE. 27 W.
RGE. 28 W
TWP. 10
TWP. 9
TWP. 8
TWP. 7
TWP. 6
TWP. 5
ASSINIBOINE RIVER
SOURIS RIVER
SOURIS
OAK LAKE
1
2
22
250
345
83
N
0
6
MILES

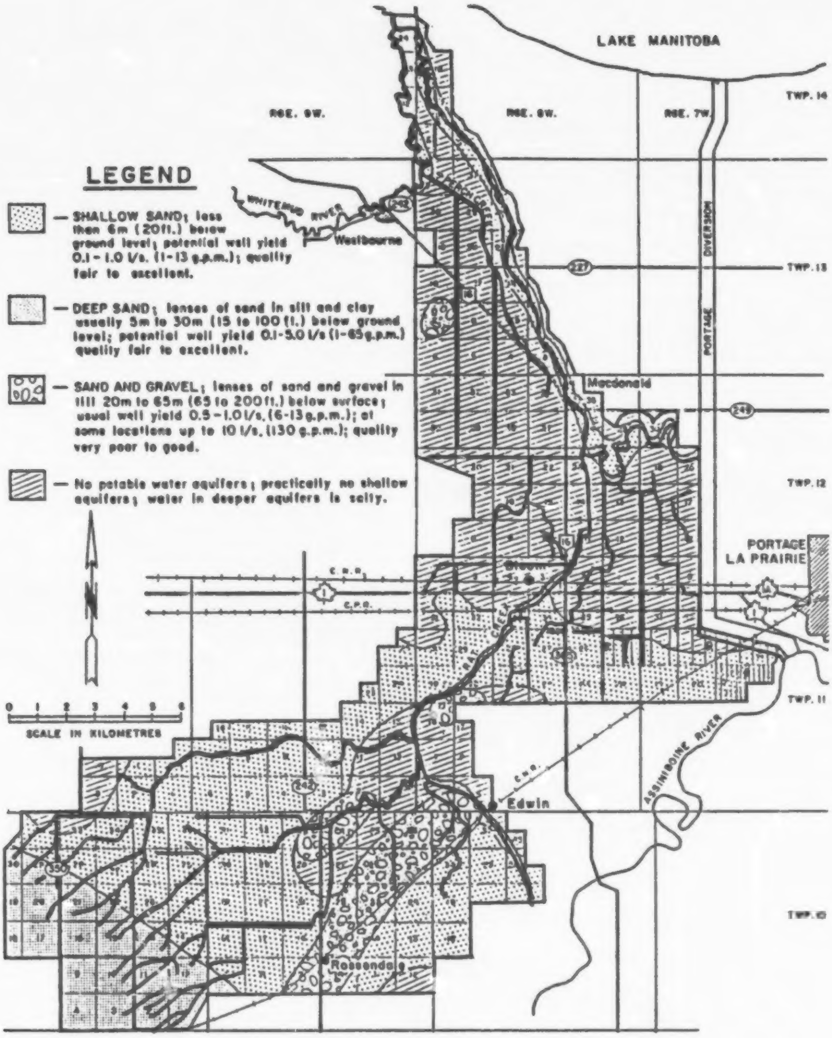
OAK LAKE
AQUIFER MONITORING STATION

FIGURE 6


LAKE MANITOBA
TWP. 14
RGE. 9W.
RGE. 8W.
RGE. 7W.
LEGEND
▨ — SHALLOW SAND; less than 6m (20ft.) below ground level; potential well yield 0.1 - 1.0 l/s. (1-13 g.p.m.); quality fair to excellent.
▨ — DEEP SAND; lenses of sand in silt and clay usually 5m to 30m (15 to 100 ft.) below ground level; potential well yield 0.1-5.0 l/s (1-65 g.p.m.) quality fair to excellent.
▨ — SAND AND GRAVEL; lenses of sand and gravel in till 20m to 65m (65 to 200 ft.) below surface; usual well yield 0.5 - 1.0 l/s. (6-13 g.p.m.); at some locations up to 10 l/s. (130 g.p.m.); quality very poor to good.
▨ — No potable water aquifers; practically no shallow aquifers; water in deeper aquifers is salty.
WHITEMUD RIVER
Westbourne
242
227
TWP. 13
PORTAGE DIVERSION
Macdonald
248
TWP. 12
PORTAGE LA PRAIRIE
Bloom
C.N.R.
C.P.R.
1
1A
16
305
N
0 1 2 3 4 5 6
SCALE IN KILOMETRES
TWP. 11
ASSINIBOINE RIVER
C.N.R.
Edwin
TWP. 10
Rossendale

AQUIFERS IN THE RAT CREEK WATERSHED

FIGURE 7


LAKE MANITOBA
RGE. 9W.
RGE. 8W.
RGE. 7W.
TWP. 14
TWP. 13
TWP. 12
TWP. 11
TWP. 10
LEGEND
▒ — SHALLOW SAND; less than 6m (20ft.) below ground level; potential well yield 0.1 - 1.0 l/s. (1-13 g.p.m.); quality fair to excellent.
░ — DEEP SAND; lenses of sand in silt and clay usually 5m to 30m (15 to 100 ft.) below ground level; potential well yield 0.1-5.0 l/s (1-65 g.p.m.) quality fair to excellent.
○ — SAND AND GRAVEL; lenses of sand and gravel in till 20m to 65m (65 to 200 ft.) below surface; usual well yield 0.5 - 1.0 l/s. (6-13 g.p.m.); at some locations up to 10 l/s. (130 g.p.m.); quality very poor to good.
▨ — No potable water aquifers; practically no shallow aquifers; water in deeper aquifers is salty.
N
0 1 2 3 4 5 6
SCALE IN KILOMETRES
WHITEMUD RIVER
Westbourne
PORTAGE DIVERSION
Macdonald
PORTAGE LA PRAIRIE
C.N.R.
C.P.R.
RAT CREEK
ASSINIBOINE RIVER
Edwin
Rossendale
242
227
240
1
1A
350

DRAINS AND AQUIFERS
IN THE RAT CREEK WATERSHED

FIGURE 8

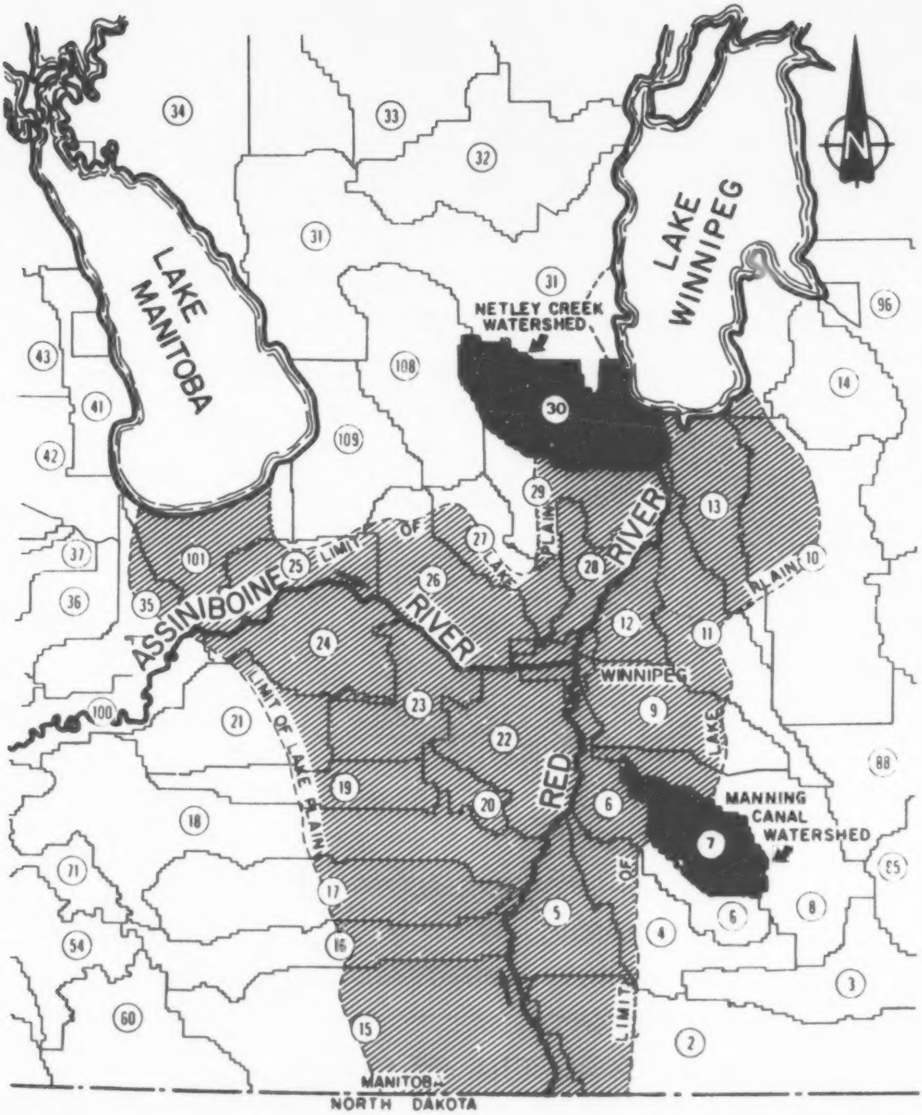
CHARACTERISTICS OF A TYPICAL RECHARGE AREA.

- FOUND IN UPPER PARTS OF WATERSHED.
- ZONE OF SATURATION WELL BELOW LAND SURFACE.
- WATER TABLE CONDITIONS COMMON.
- LARGE SEASONAL CHANGE IN GROUNDWATER LEVELS.
- SOIL SALINITY LOW TO MODERATE.
- GOOD INTERNAL SOIL DRAINAGE.
- WATER LOGGED SOILS ARE UNCOMMON.

CHARACTERISTICS OF A TYPICAL DISCHARGE AREA.

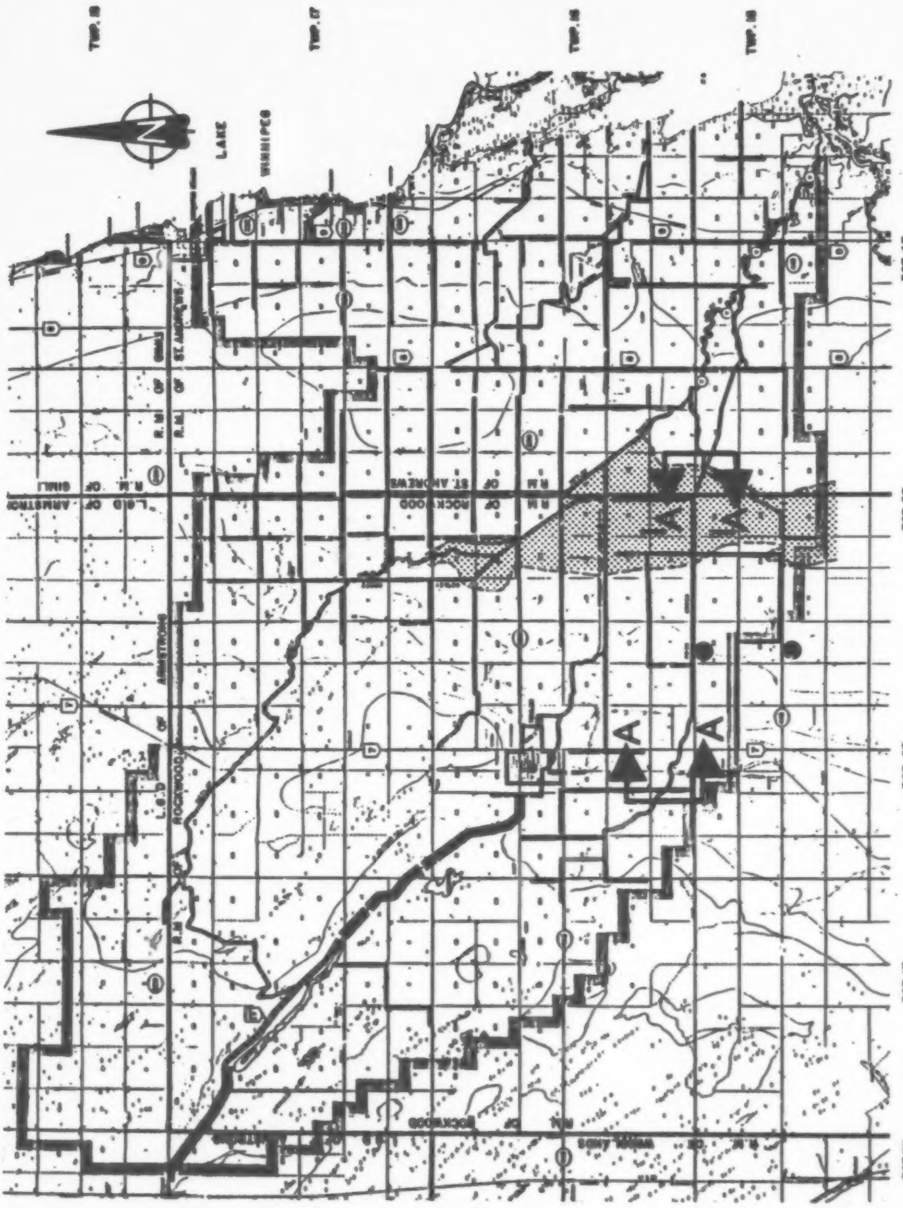
- FOUND IN LOWER PARTS OF WATERSHED.
- ZONE OF SATURATION NEAR LAND SURFACE.
- ARTESIAN CONDITIONS COMMON.
- SMALL SEASONAL CHANGE IN GROUNDWATER LEVELS.
- SOIL SALINITY MODERATE TO SEVERE.
- SEEPAGE COMMON.
- WATER LOGGED SOILS ARE COMMON.

FIGURE 9


N
LAKE MANITOBA
LAKE WINNIPEG
NETLEY CREEK WATERSHED
MANNING CANAL WATERSHED
WINNIPEG
ASSINIBOINE
RIVER
RED
RIVER
LIMIT OF LAKE PLAIN
LIMIT OF LAKE PLAIN
LIMIT OF LAKE PLAIN
LIMIT OF LAKE PLAIN
MANITOBA
NORTH DAKOTA
34
33
32
31
31
96
43
108
14
41
30
109
42
29
13
37
101
25
27
28
10
36
35
26
12
11
24
100
23
9
21
22
88
19
20
6
18
7
71
17
5
8
85
6
4
54
16
3
60
15
2

ARTESIAN AQUIFER MODIFICATION

FIGURE 10

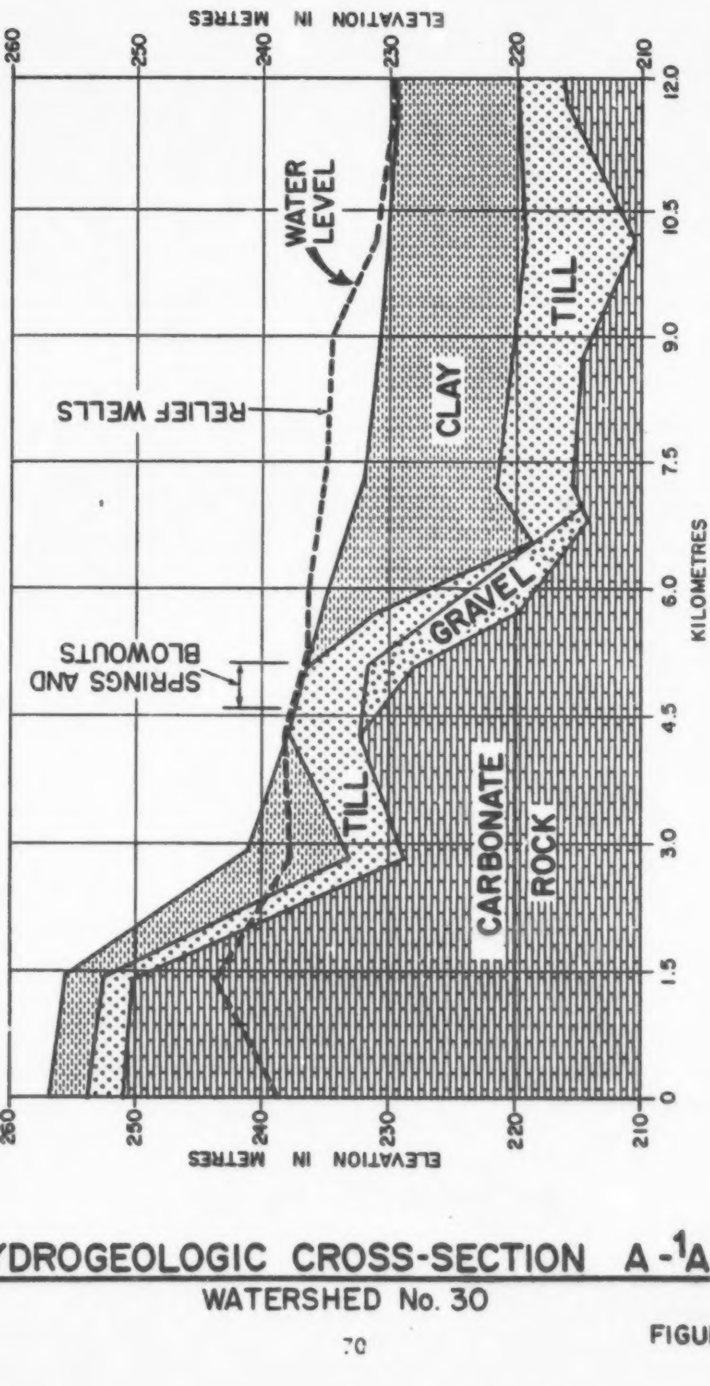

TWP.18
TWP.17
TWP.16
TWP.15
LAKE
WINNIPEG
R.M. OF GIMLI
R.M. OF ST. ANDREWS
R.M. OF ROCKWOOD
L.G.D. OF ARMSTRONG
RGE.4E
RGE.3E
RGE.2E
RGE.1E
RGE.1W
A
A
A
A

WATERSHED No. 30

LEGEND

Great Marsh (1874) ▨
Springs (1874) ----●

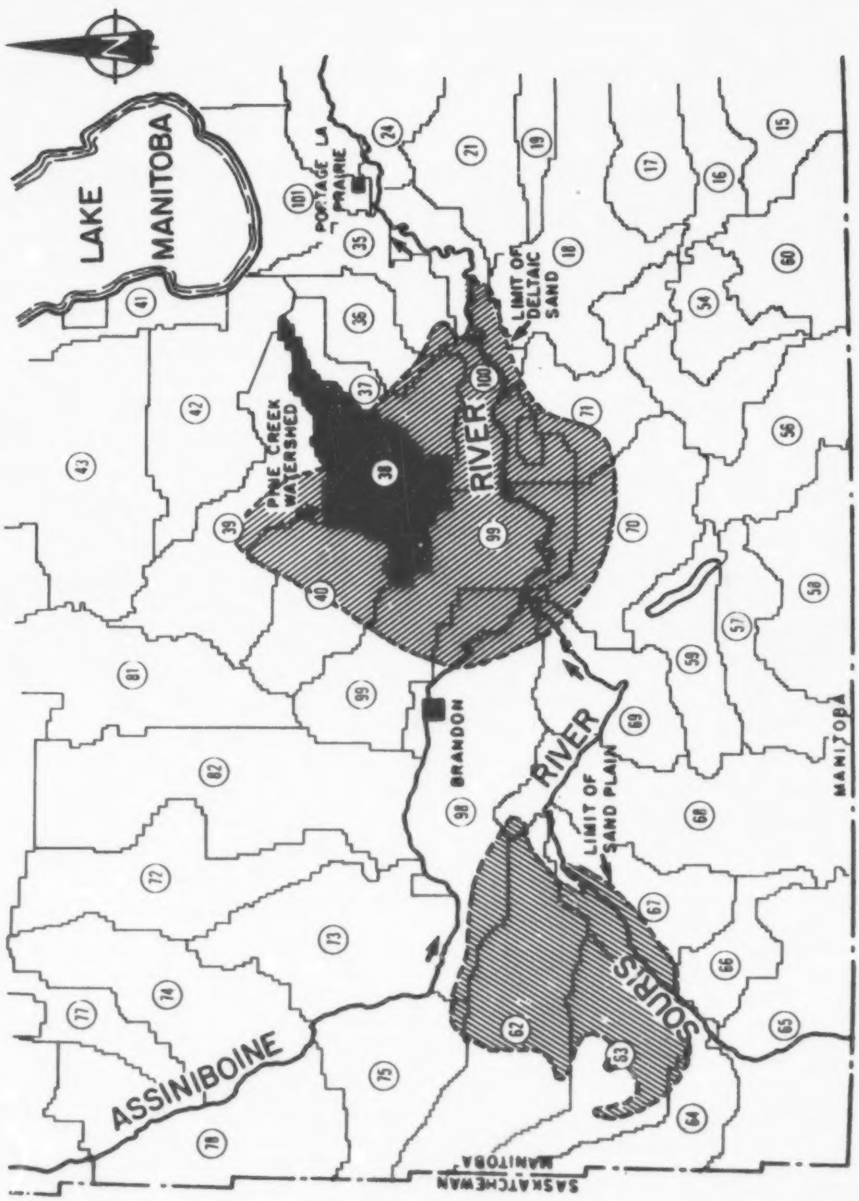
FIGURE 11


ELEVATION IN METRES
260
250
240
230
220
210
WATER LEVEL
RELIEF WELLS
SPRINGS AND BLOWOUTS
CLAY
TILL
GRAVEL
TILL
CARBONATE ROCK
0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
KILOMETRES

HYDROGEOLOGIC CROSS-SECTION A-^{1}A

WATERSHED No. 30

FIGURE 12


LAKE MANITOBA
PORTAGE LA PRAIRIE
LIMIT OF DELTAIC SAND
PINE CREEK WATERSHED
RIVER
BRANDON
RIVER
LIMIT OF SAND PLAIN
SOURIS
ASSINIBOINE
SASKATCHEWAN
MANITOBA
MANITOBA
15
16
17
18
19
21
24
35
36
37
38
39
40
41
42
43
54
56
57
58
59
60
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63
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67
68
69
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71
72
73
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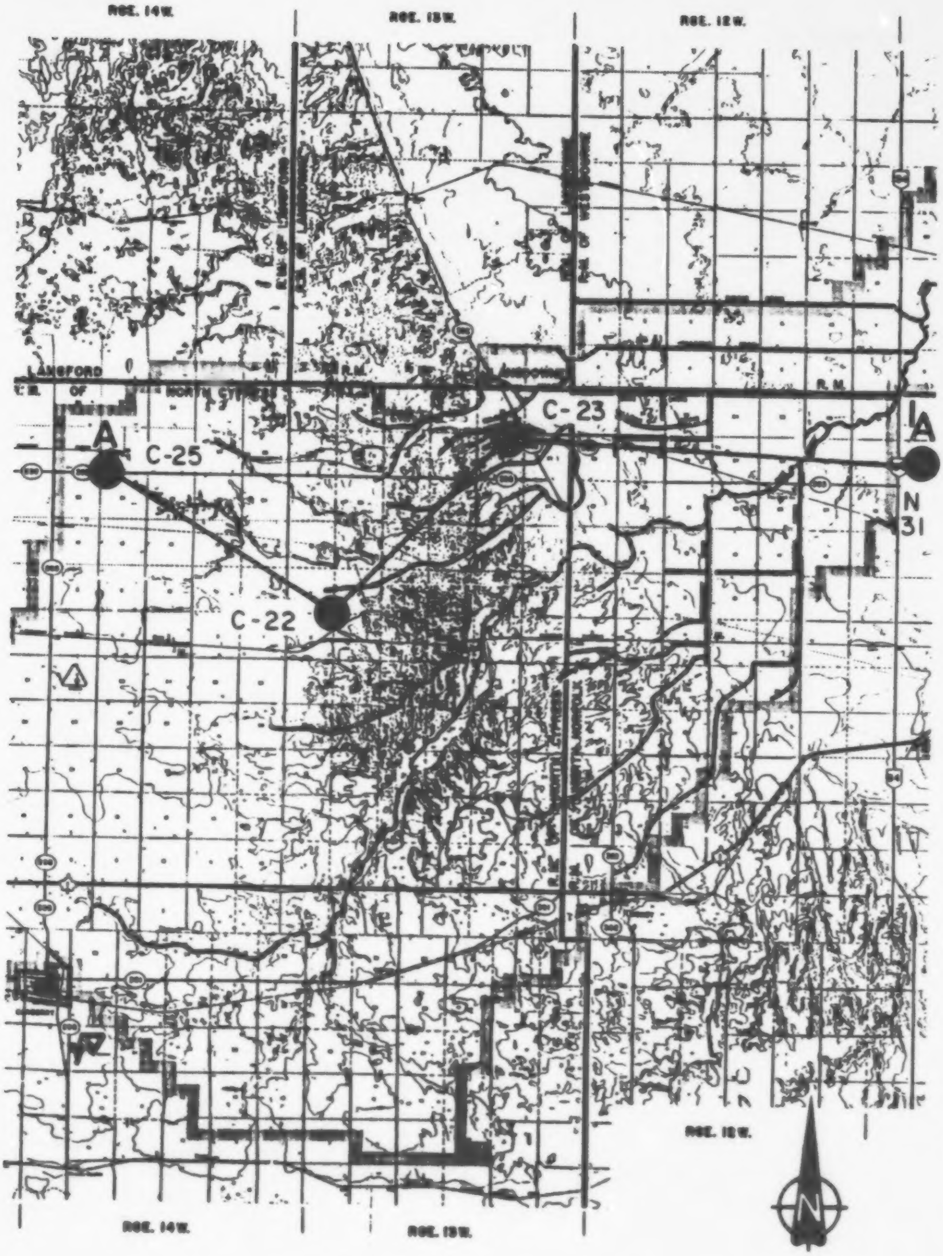
75
77
78
81
82
98
99
99
100
101

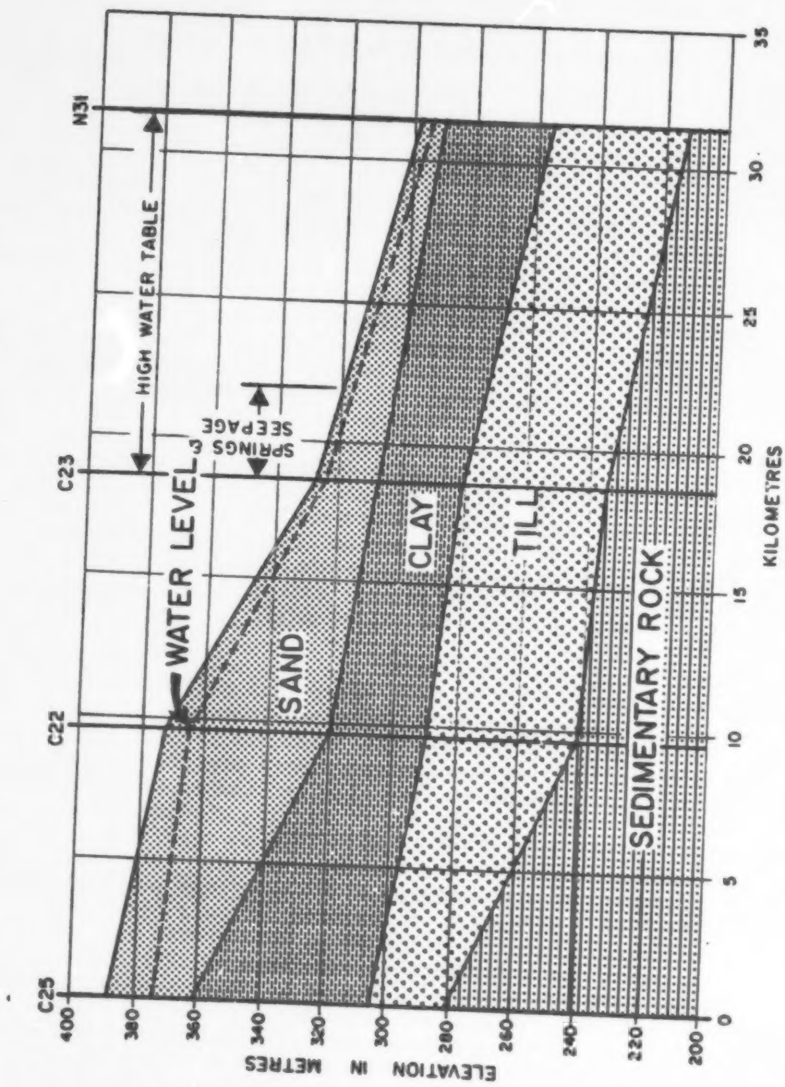
WATERTABLE AQUIFER MODIFICATION

FIGURE 13


RGE. 14 W.
RGE. 13 W.
RGE. 12 W.
LANGFORD
R.M. OF
NORTH CYPRESS
R.M.
C-23
A
C-25
C-22
A
N
31
RGE. 12 W.
RGE. 14 W.
RGE. 13 W.
N

WATERSHED No. 38

FIGURE 14


C25
C22
C23
N31
HIGH WATER TABLE
SPRINGS & SEEPAGE
WATER LEVEL
SAND
CLAY
TILL
SEDIMENTARY ROCK
400
380
360
340
320
300
280
260
240
220
200
ELEVATION IN METRES
0
5
10
15
20
25
30
35
KILOMETRES

HYDROGEOLOGIC CROSS-SECTION A-^{1}A

WATERSHED NO. 38

FIGURE 15

SOIL WATER-SOIL TEMPERATURE INTERACTIONS IN THE GERMINATION AND EMERGENCE OF CORN (*Zea mays L.*)

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This study arose out of a need to predict, with mathematical models, the time to emergence of corn under field conditions. Often after planting both water and temperature in the soil are changing and are usually limiting. Examination of the literature showed that it would not be possible to use existing information to model emergence of corn. Either the studies that have been conducted with soil water have been at constant or optimum temperature (Hadas 1970; Williams and Shaykewich 1971; Pawloski and Shaykewich 1972) or the studies with soil temperature have been conducted at optimum water (Blacklow 1972; Warrington and Kanemasu 1983). Although some work involving the effect of both water and temperature on germination of wheat (Lindstrom et al. 1976) and cotton (Wanjura and Buxton 1972) has been done, to the authors' knowledge, there have been no studies of the combined effects of water and temperature on germination and emergence of corn. The subject of the current study was to evaluate the interaction of water and temperature in the germination and emergence processes with a view to developing a mathematical predictive model.

The objectives of the study were:
(i) to measure the effect of soil water and soil temperature on the time to, and rate of, germination and emergence,
(ii) to mathematically describe the combined influence of water and temperature on germination and emergence. A measure of the usefulness of a mathematical equation to estimate the time to emergence would be its versatility - ease of use under varying conditions such as with different soil types and hybrids. With this in mind, two soil types- a loamy sand and a clay loam - and three hybrids - two early maturing hybrids, Pioneer 3995 and Northrup King 403, and one medium maturing hybrid, Pride 1108 - were used in the study.

MATERIALS AND METHODS

The two soils used in this study were the Almasippi loamy sand and Carroll clay loam. Moisture characteristic curves were determined for each soil using the pressure membrane method. The upper - field capacity (FC) - and lower - permanent wilting percentage (PWP) - limits of available water were calculated from the 33 (θ_{33}) and 1500 (θ_{1500}), kPa water contents using the following equations (Shaykewich, 1965):

$$FC = 8.28 + 0.654\ (\theta_{33}) \qquad (1)$$

$$PWP = 0.021 + 0.775\ (\theta_{1500}) \qquad (2)$$

Soil characteristics are given in Table 1.

Water was thoroughly mixed (using a plant mister and cement mixer) with each soil to obtain water contents within the corresponding available water range. The wetted soil was then stored in covered 6-litre plastic pots at the desired temperature for 1 week before planting. The constant temperatures were 15±0.5, 19±1.0, 25±0.5 and 30.5±0.5°C.

Thirty seeds, 10 of each hybrid, were planted at the desired depth in each pot. Each seed layer was divided into three equal parts, each part occupied by the seeds of one hybrid. The soil-water mixtures were packed uniformly to bulk densities of 1050 kg m^{-3} for the Carroll clay loam, and 1380 kg m^{-3} for the Almasippi loamy sand.

(a) Germination

Approximately 5 kg (clay loam) or 6 kg (loamy sand) of soil with an appropriate amount of water were added to each pot. For water contents greater than 50% of the maximum available water, four layers of seeds were sown per pot, with each water content duplicated. For lower water contents three layers of seeds were sown per pot, with each water content triplicated. At each harvest, 20 seeds of each hybrid (two layers) were sampled from each pot. This allowed four individual harvests per water content. At the higher temperatures, samplings had to be done every 6 to 24 hours depending upon the water content; at the lower temperatures sampling was done every 12 to 48 hours. Those seeds that showed any sign of radicle protrusion through the seed coat were counted as germinated. The pots were covered to prevent evaporation and opened twice daily for aeration purposes.

(b) Emergence

The seeds were sown 5 cm deep in 12 cm of soil in each pot. Each water content was duplicated. Depending upon temperature and water content, two to four emergence counts per day were made until a constant emergence count for all hybrids was observed.

RESULTS

Planting to 50% Germination A decrease in either temperature or water content increased time to germination (Table 2). Generally less time was needed for germination of Northrup King 403 than for Pride 1108 while Pioneer 3995 required the longest time to germinate. Pioneer 3995 has a larger seed, 0.39 g/seed compared to 0.25 g/seed for both Pride 1108 and Northrup King 403. Longer times may be needed for Pioneer 3995 to reach a critical water content to begin the germination process. In the clay loam soil at the two lower temperatures, high water contents caused slight delays in germination of Pride 1108 and Northrup King 403. This delay may indicate aeration problems for the smaller seeds at low temperature and high soil water content.

The reciprocal of time to germination is the germination rate. An example of the rate curves for germination is shown in Figure 1. At each temperature in each soil, the data were fitted to the following model:

$$Rgerm = Rmax\{1 - \exp[-k(\theta - \theta o)]\} \qquad (3)$$

where Rgerm = germination rate (seeds per hour), Rmax = maximum germination rate at optimum water, k = rate constant, θ = volumetric water content, and θo = threshold water content below which Rgerm is zero.

The parameters obtained when Equation (3) was iteratively fitted are shown in Table 3. The curves fit the data very well, with all R^2 values in excess of 0.97. For a given soil, θo increased slightly with a decrease in temperature but is clearly very closely approximated by PWP calculated from Equation 2 (Table 1). θo for the loamy sand was greater than the -1500 kPa water content, while for the clay loam it was lower. One would expect that in the region of -1500 kPa, hydraulic conductivity would be higher in the clay loam soil. Thus it is possible that the difference between θo and the -1500 kPa water content for the two soils reflects the influence of hydraulic conductivity on the biological wilting point.

The rate constant, k, generally increased with a decrease in temperature. The rate constants for the loamy sand were generally slightly greater than those for the clay loam.

Rmax decreased with decreasing temperature. For a given hybrid and temperature, Rmax was reasonably independent of soil type. For a given temperature, the differences in Rmax between hybrids were significant.

Because θo was closely approximated by PWP, it was replaced by PWP in Equation 3. The term θ - PWP then represents the amount of available water remaining in the soil. It is quite common to express this amount as a fraction of the potential available water, i.e. field capacity (FC) minus PWP. Thus the term relative available water (RAW) can be defined as:

$$\mathrm{RAW} = (\theta - \mathrm{PWP})/(\mathrm{FC} - \mathrm{PWP}) \qquad (4)$$

in which θ is current water content. For each hybrid, data from the two soils were combined and germination rate was plotted as a function of relative available water (e.g. Figure 2). The data was then fitted to the model:

$$\mathrm{Rgerm} = \mathrm{Rmax}\{1 - \exp[-S\ \mathrm{RAW}]\} \qquad (5)$$

where S is now the rate constant appropriate to RAW. The parameters are given in Table 4.

Germination rate shows a region of constant value above a certain RAW, i.e. maximum rate of germination is achieved at some water content well below field capacity. This plateau region extended to lower water contents as temperature decreased.

The rate constant, S, generally increased slightly with decreasing temperature (Table 4). Rmax decreased with decreasing temperature. Rmax for Northrup King 403 and Pride 1108 at 25°C was greater than Rmax for Pioneer 3995 at 30.5°C (Figure 3). The rate curves are thus hybrid dependent and cannot be combined further.

For a given hybrid, Rmax was a linear function of temperature (Figure 3). R^2 values of the equations in Figure 3 are all in excess of 0.91. Although S increased slightly with decreasing temperature, the relationship was not adequately described by a linear equation, the largest R^2 value obtained was 0.74 in the case of Pioneer 3995. For Northrup King 403 and Pride 1108, the lowest S value was found at 25°C, suggesting there may be a minimum at this temperature. This aspect will require further investigation.

Planting to 50% Emergence For a given temperature, emergence times increased with a decrease in volumetric water content, θ (Table 5). The difference in emergence times between the highest and lowest θ varied from 7 to 14 days, the range increasing with decreasing temperature. For the clay loam soil, seedlings emerged from soil with θ lower than that held at -1500 kPa. However, the emergence times were long and the seedlings much less vigorous than those at higher water contents. For a given temperature, the time to emergence was the shortest for Northrup King 403 and the longest for Pioneer 3995. In the case of germination, it was suggested that the longer times to germination for Pioneer 3995 may be the result of that hybrid having a substantially larger seed, and consequently requiring a much larger quantity of water to reach the same water content within the seed. The same explanation may apply to emergence.

At 15°C in the Almasippi loamy sand, the relative position of the hybrids with respect to time to emergence was reversed. In this case, Pioneer 3995 emerged slightly sooner than the other two hybrids. In general, however, time to emergence was influenced by both temperature and water in approximately the same way for all three hybrids. The variation between hybrids in time to emergence was generally less than 15%. Thus, when emergence rate (the reciprocal of time to emergence) was plotted as a function of water content, it was possible to combine the data from all three hybrids (Figure 4). The curves are similar to those for germination in that as temperature decreased, the plateau region of the curve extended to include progressively lower water contents. The data for emergence rate were fitted to the model in Equation 3, yielding the parameters in Table 6.

The maximum rate of emergence, Rmax, decreased with decreasing temperature (Table 6). For a given temperature and hybrid, Rmax did not differ appreciably between soils. Rmax differed slightly between hybrids, Northrup King 403 emerging slightly faster than Pride 1108 followed by Pioneer 3995. Again, the differences were not large. When Rmax for all three hybrids was linearly regressed on temperature, the following equation was obtained:

$$Rmax = 0.00089\ (T - 10.8) \qquad R^2 = 0.99 \qquad (6)$$

For a given soil, there was little change in θo with temperature both within and between hybrids. For the clay loam soil, θo was approximately equal to the calculated PWP, for the loamy sand it was slightly higher than PWP (Table 1). However, in both soils it would appear that PWP is a good estimate of the lower limit of availability of water for emergence. For this reason, emergence rate was plotted against relative available water (e.g. Figure 5) as had been done with germination. It should be noted that the data in Figure 5 include both soils and that the 'fit' is very good. Because differences between hybrids had been very small, all the data were combined and plotted on one graph (Figure 6). A general equation for describing emergence rate as a function of temperature and relative available water was developed by fitting the data to the model described by Equation 5 (see equations in Table 7).

The values of the rate constant, S, showed a definite increase with decreasing temperature (Table 7). The regression equation expressing this relationship is:

$$S = 8.1965 - 0.3229\ T + 0.0055\ T^2 \qquad R^2 = 0.99 \quad (7)$$

in which T is temperature in degrees C. If one examines the model (Equation 5), one observes that S occurs in the negative exponential, and thus as soil temperature decreases, emergence becomes less sensitive to changes in relative available water.

The ratios of Rmax for emergence to Rmax for germination (Table 7) show that a much greater portion of the total time to emergence is required for germination for Pioneer 3995 than for the other two hybrids. It should also be noted that this ratio decreased with decreases in temperature. This means that the stage from germination to emergence is more temperature dependent than that from planting to germination.

DISCUSSION

Germination The results show that germination of the three hybrids of corn used was adequately described by a relationship involving temperature and the conventional concept of available water, i.e. between field capacity and permanent wilting percentage. The relationships were hybrid dependent, the dependency apparently being related to seed size, with larger seeds requiring longer times to germinate. Soil water content had the greatest influence on germination rate at high temperature, e.g. 30.5°C, and almost no influence at low temperature, e.g. 15°C.

Emergence Temperature and relative available water provided a good estimate of emergence rate. Further, whereas germination rate as a function of water and temperature was found to be hybrid dependent, emergence rate of all three hybrids could be adequately described by one equation. Although there is no doubt that properties such as water potential and hydraulic conductivity have an important influence on germination and emergence of seeds, it is very convenient that the response of seeds to water can be described adequately by the parameter relative available water. In this case, one need only determine FC, and PWP, or alternatively the -33 kPa and -1500 kPa equilibrium water contents. These determinations are much simpler than those for water potential and hydraulic conductivity.

Although it is likely that the responses of different hybrids to water and temperature would vary, the data gathered here could be used to get a first approximation of corn emergence. A possible procedure might be as follows:

1. Obtain an average daily soil temperature at seed depth. Using equations 6 and 7, calculate the values of Rmax and k, respectively.
2. Obtain a measure or estimate of soil water content and calculate

relative available water.

3. Input the above data into the model in Equation 5 to calculate hourly, and then daily, emergence rate. When the sum of the daily emergence rates is unity or greater, the crop should have emerged.

ACKNOWLEDGMENTS

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Table 1. Soil characteristics for Carroll clay loam and Almasippi loamy sand soils.

Soil Type	Bulk density (kg m^{-3})	Water content (m^3/m^3) at -33 kPa	FC	-1500 kPa	PWP
Carroll CL	1050	.500	.430	.159	.130
Almasippi LS	1380	.268	.356	.052	.056

Table 2. Time (hrs) to 50% germination as a function of volumetric water content and temperature.

Temperature (°C)	Hybrid	Volumetric water content (m^3 water/m^3 soil)					
Carroll clay loam							
		.405	.302	.264	.205	.156	.126
30.5	Pioneer 3995	25	25	29	36	61	133
	Northrup King 403	15	16	18	24	45	114
	Pride 1108	18	19	22	29	53	158
25		.430	.321	.278	.222	.170	.137
	Pioneer 3995	31	33	37	45	58	116
	Northrup King 403	17	17	19	27	46	123
	Pride 1108	23	26	30	37	65	123
19		.440	.316	.272	.214	.173	.140
	Pioneer 3995	47	45	54	57	94	179
	Northrup King 403	32	28	35	39	60	149
	Pride 1108	37	34	43	52	91	171
15		.413	.315	.271	.215	.171	.137
	Pioneer 3995	65	72	77	86	133	-
	Northrup King 403	54	50	48	57	97	426
	Pride 1108	67	62	60	81	135	-
Almasippi loamy sand							
			.352	.210	.134	.106	.087
30.5	Pioneer 3995		22	21	40	48	73
	Northrup King 403		15	17	20	36	57
	Pride 1108		18	21	30	41	75
25			.342	.227	.146	.126	.104
	Pioneer 3995		33	35	43	56	72
	Northrup King 403		17	19	26	35	48
	Pride 1108		22	25	40	47	66
19			.324	.235	.161	.104	.081
	Pioneer 3995		49	50	55	100	180
	Northrup King 403		28	31	34	66	151
	Pride 1108		33	36	43	90	186
15			.368	.222	.146	.115	.097
	Pioneer 3995		70	74	86	121	172
	Northrup King 403		41	42	53	85	123
	Pride 1108		57	61	68	106	168

Table 3. Threshold volumetric water content, θo, rate constant, k, and maximum rate of germination, Rmax, as obtained by iterative fitting of the model $Rgerm = Rmax\{1-\exp[-k(\theta-\theta o)]\}$.

Hybrid	Temperature (°C)	$\theta o(m^3/m^3)$ Carroll	$\theta o(m^3/m^3)$ Almasippi	k Carroll	k Almasippi	$Rmax(hour^{-1})$ Carroll	$Rmax(hour^{-1})$ Almasippi
Pioneer 3995	30.5	.109	.065	11.16	13.54	0.0428	0.0489
	25	.104	.070	9.88	17.36	0.0336	0.0306
	19	.122	.066	14.72	19.21	0.0221	0.0208
	15	.118	.074	13.21	22.16	0.0154	0.0142
	Average	.113	.069	12.24	18.07		
Northrup King 403	30.5	.114	.072	9.56	19.33	0.0725	0.0659
	25	.122	.073	9.41	13.01	0.0653	0.0608
	19	.127	.070	16.11	17.28	0.0335	0.0356
	15	.132	.079	22.03	19.92	0.0212	0.0248
	Average	.124	.072	14.28	17.39		
Pride 1108	30.5	.116	.062	9.68	10.92	0.0603	0.0609
	25	.113	.067	7.17	9.58	0.0488	0.0495
	19	.124	.068	11.57	13.69	0.0295	0.0313
	15	.147	.081	25.39	25.67	0.0160	0.0173
	Average	.125	.070	13.44	14.97		
	Overall Average	.121	.070	13.32	16.80		

Table 4. Maximum germination rate (Rmax) and rate constant (S) for each hybrid-temperature combination in the model: Rgerm = Rmax{1-exp[-S RAW]}.

Temperature (°C)	Rmax (hour^{-1})	S	R^2
Pioneer 3995			
30.5	0.0455	3.79	0.98
25	0.0312	4.38	0.99
19	0.0216	4.85	0.99
15	0.0149	4.59	0.99
Northrup King 403			
30.5	0.0694	3.74	0.99
25	0.0643	2.98	0.99
19	0.0351	4.28	0.99
15	0.0228	4.58	0.98
Pride 1108			
30.5	0.0605	3.18	0.99
25	0.0483	2.62	0.99
19	0.0308	3.43	0.99
15	0.0173	4.51	0.99

Table 5. Time (hrs) to 50% emergence as a function of volumetric water content and temperature.

Temperature ($^{\circ}$C)	Hybrid	Volumetric water content (m^3 water/m^3 soil)					
Carroll clay loam							
30.5		.436	.341	.286	.215	.184	.149
	Pioneer 3995	63	70	74	90	130	241
	Northrup King 403	56	59	63	85	119	214
	Pride 1108	59	61	65	84	127	242
25			.366	.294	.225	.176	.156
	Pioneer 3995		89	100	124	187	262
	Northrup King 403		82	87	109	161	248
	Pride 1108		85	92	116	169	248
19		.418	.310	.254	.199	.167	.159
	Pioneer 3995	151	164	178	249	351	453
	Northrup King 403	131	146	165	224	305	429
	Prie 1108	135	150	173	248	424	-
15		.335	.316	.238	.200	.186	.161
	Pioneer 3995	284	285	303	385	378	643
	Northrup King 403	269	268	283	361	376	-
	Pride 1108	277	286	292	361	376	-
Almasippi loamy sand							
30.5			.331	.228	.153	.108	.095
	Pioneer 3995		63	70	84	161	186
	Northrup King 403		60	69	86	147	183
	Pride 1108		60	62	82	147	183
25		.346	.225	.152	.120	.091	.086
	Pioneer 3995	85	96	121	147	291	407
	Northrup King 403	74	84	107	137	274	311
	Pride 1108	80	84	105	141	285	-
19			.348	.222	.155	.123	.097
	Pioneer 3995		156	179	192	243	455
	Northrup King 403		142	150	178	239	437
	Pride 1108		145	153	162	213	463
15			.327	.237	.166	.135	.111
	Pioneer 3995		258	285	327	416	543
	Northrup King 403		258	298	356	455	617
	Pride 1108		270	303	381	527	650

Table 6. Threshold volumetric water content, θo, rate constant, k, and maximum rate of emergence, Rmax, as obtained by iterative fitting of the model Remer = Rmax{1-exp[-k(θ-θo)]}.

Hybrid	Temperature (^oC)	$\theta o(m^3/m^3)$		k		Rmax($hour^{-1}$)	
		Carroll	Almasippi	Carroll	Almasippi	Carroll	Almasippi
Pioneer 3995	30.5	.124	.069	11.77	14.82	0.0160	0.0161
	25	.118	.069	9.96	15.62	0.0122	0.0117
	19	.125	.077	12.80	23.15	0.0068	0.0062
	15	.128	.067	20.41	14.26	0.0036	0.0039
Average		.124	.071	13.74	17.00		
Northrup King 403	30.5	.124	.064	10.79	11.93	0.0187	0.0173
	25	.127	.067	13.30	13.55	0.0128	0.0137
	19	.125	.078	11.38	20.06	0.0079	0.0071
	15	.136	.064	23.10	10.98	0.0038	0.0041
Average		.128	.068	14.64	14.13		
Pride 1108	30.5	.129	.072	12.37	15.15	0.0176	0.0173
	25	.122	.073	11.51	17.58	0.0125	0.0127
	19	.136	.085	11.78	31.66	0.0077	0.0068
	15	.134	.065	24.44	9.99	0.0036	0.0040
Average		.130	.074	15.03	18.60		
Overall Average		.127	.071	14.47	16.50		

Table 7. Maximum emergence rate (Rmax) and rate constant (S) for each hybrid-temperature combination in the model: Remer = Rmax[1-exp[-S RAW]].

Temperature (°C)	Rmax (hour^{-1})	Ratio†	S	R^2
Pioneer 3995				
30.5	.0163	.36	3.60	0.99
25	.0121	.38	3.53	0.99
19	.0066	.31	4.13	0.99
15	.0037	.25	5.12	0.99
Northrup King 403				
30.5	.0182	.26	3.30	0.99
25	.0136	.27	3.51	0.99
19	.0076	.22	3.78	0.99
15	.0039	.17	4.31	0.97
Pride 1108				
30.5	.0179	.29	3.43	0.99
25	.0128	.26	3.84	0.99
19	.0075	.24	3.74	0.99
15	.0037	.22	4.30	0.98
ALL HYBRIDS COMBINED				
30.5	.0175		3.44	0.99
25	.0128		3.62	0.99
19	.0072		3.88	0.99
15	.0037		4.61	0.99

† Ratio = Ratio of Rmax for emergence divided by Rmax for germination.

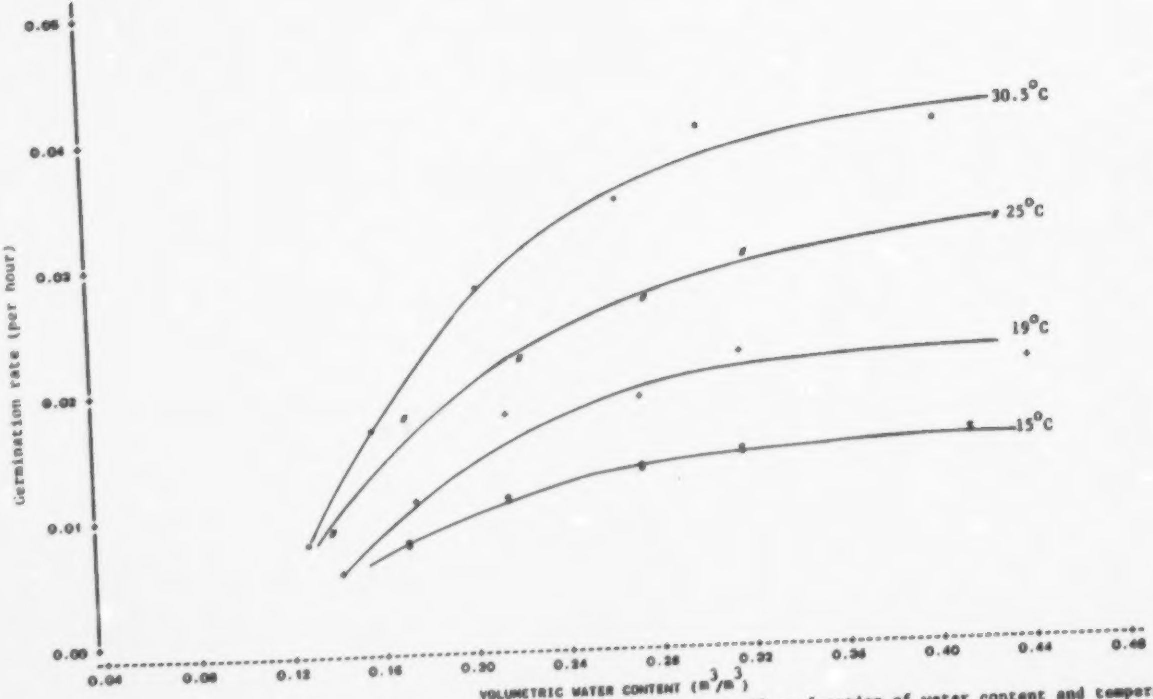


Figure 1. Germination rate of Pioneer 3995 in Carroll clay clay soil as function of water content and temperature.

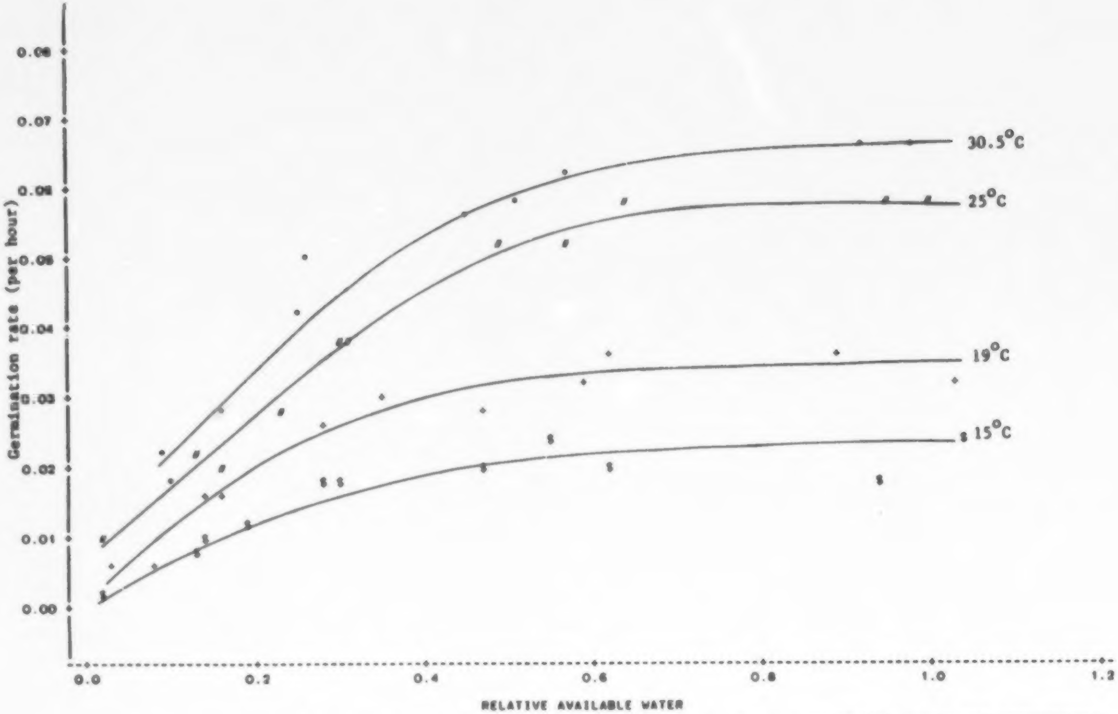


Figure 2. Germination rate of Northrup King 403 as a function of relative available water and temperature.

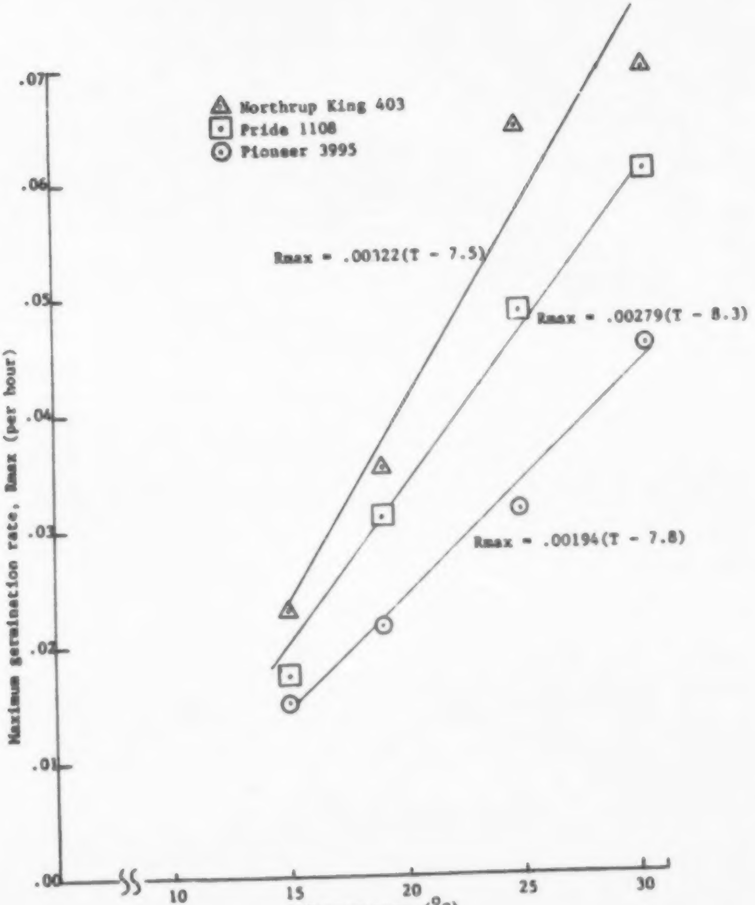


Figure 3. Maximum germination rate as a function of temperature.

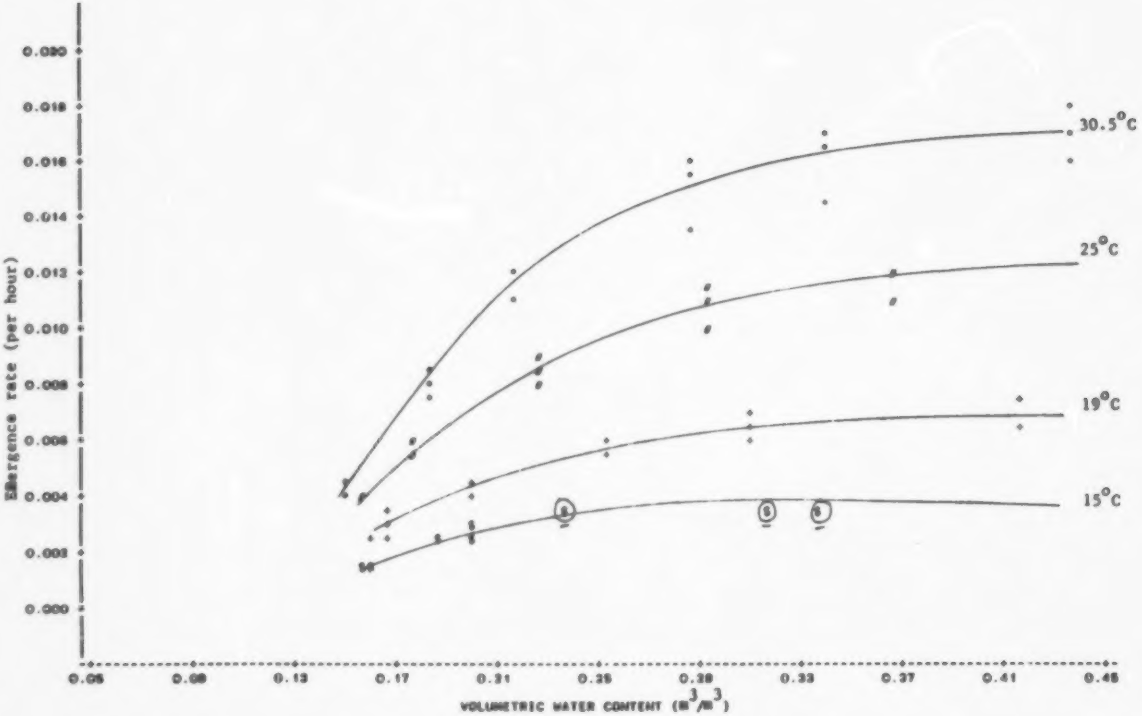


Figure 4. Emergence rate of all three hybrids as a function of water content in Carroll clay loam.

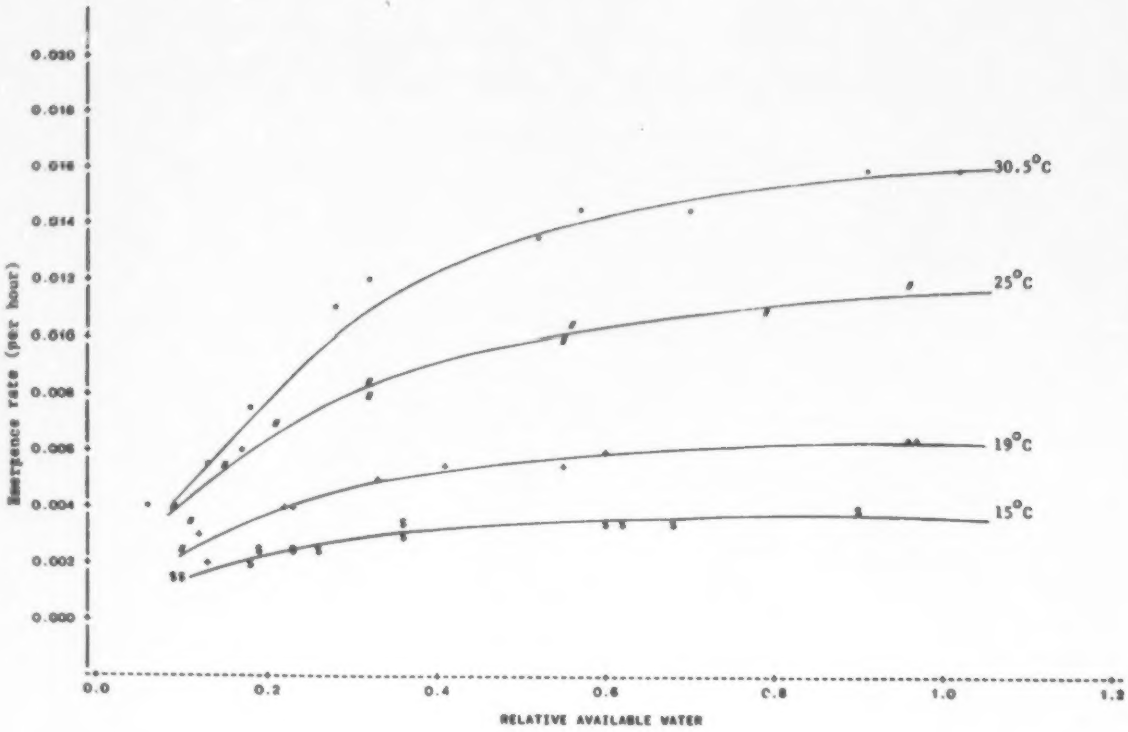


Figure 5. Emergence rate of Pioneer 3995 as a function of relative available water in both soils.

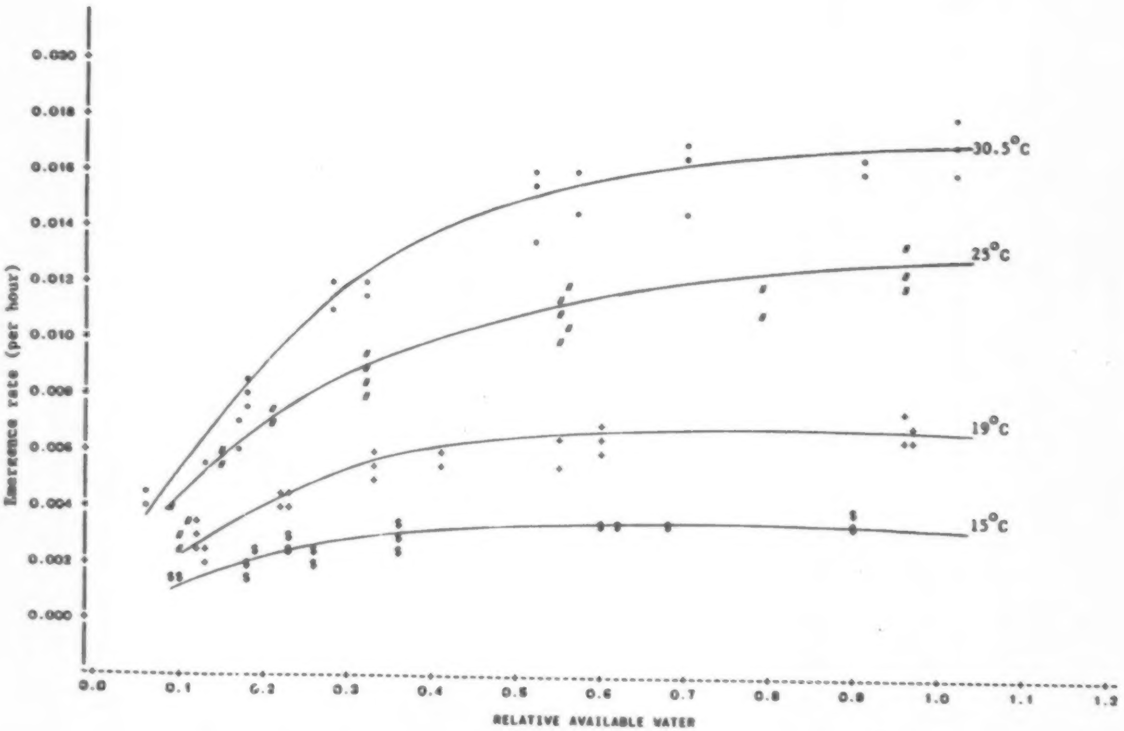


Figure 6. Emergence rate of all three hybrids as a function of relative available water in both soils.

1984 FALL MOISTURE MAP

ASSUMPTIONS:

(1) Available soil moisture supply as of September 9 for most well drained soils under stubble in Manitoba was near permanent wilting point to 90 cm.

(2) No surface runoff of precipitation occurred between September 10 and October 29.

(3) Nearly all precipitation between September 10 and October 29 was stored in the soils.

METHODS:

(1) Depth of wetted soil to field capacity was calculated using soil texture-water holding capacity relationships.

(2) Depth of soil at field capacity was calculated for each (27) weather station.

(3) Contour map of precipitation distribution was plotted by computer.

(4) Map showing depth of soil at field capacity was plotted by computer and later adjusted using a generalized soil texture map.

INTERPRETATION:

The map reflects the minimum depth of moist soil in most Manitoba soils as of November 1, 1984. For example, the region labelled 90 cm (3 ft.) is thoroughly wet (at capacity) to 90 cm for all practical purposes. This represents an ideal condition for the soil. Average rainfall in 1985 in these areas should produce a better than average crop. If rainfall is higher than average there is a risk of crop damage due to excess moisture.

At the other extreme, areas labelled 60 cm will probably benefit from higher than normal rainfall next summer. It should be emphasized that this still represents a relatively good situation, probably much better than we have had for the last few years.

RECOMMENDATIONS:

Because of the relatively good stored soil moisture situation, farmers should be encouraged to add ample nutrients (fertilizer) when planting crops next spring. In most cases 50 to 75 kg N /ha should be added to stubble seeded crops along with 30 to 45 kg P_2O_5/ha for cereals or 20 kg/ha P_2O_5 for oilseeds. On coarse textured soils potash may be be applied at 15 to 70 kg K_2O/ha while on well drained soils 15 to 30 kg S/ha may be required.

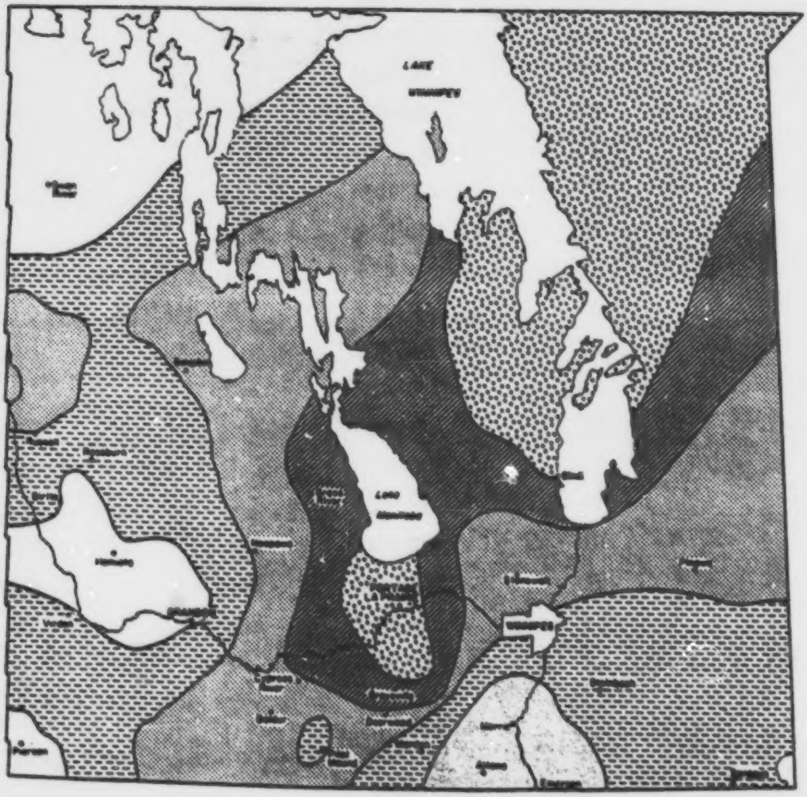
Soil tests indicate that in western areas of the prairie which experienced drought conditions in 1984 residual soil nitrate nitrogen is above average. In these areas lower rates of fertilizer nitrogen may be sufficient to produce optimum yields.

Sept.10-Oct.29 Precipitation		Station	At Nov.1 Depth of Moist Soil	
mm	in.		cm	in.
104	4.2	ALTONA	48	19
172	6.9	BALDUR	81	32
123	4.9	BIRTLE	58	23
115	4.6	BRANDON	54	21
180	7.2	CYPRESS RIVER	83	33
153	6.1	DAUPHIN	71	28
184	7.4	DEERWOOD	85	34
120	4.8	EMERSON	55	22
202	8.1	GIMLI	93	37
182	7.3	GRASS RIVER	91	36
212	8.5	GRAYSVILLE	100	39
126	5.0	HAMIOTA	59	23
139	5.6	MORDEN	65	26
106	4.2	MORRIS	49	19
153	6.1	NEEPAWA	72	28
149	6.0	PIERSON	72	28
149	6.0	PILOT MOUND	69	27
* 158	6.2	PINAWA	75	30
210	8.4	PORTAGE	99	39
134	5.4	ROSSBURN	63	25
156	6.2	RUSSELL	73	29
135	5.2	SPRAGUE	107	41
135	5.4	STEINBACH	68	27
155	6.2	STONEWALL	72	28
* 182	7.1	SWAN RIVER	91	36
122	4.9	VIRDEN	57	23
153	6.1	WINNIPEG	71	28

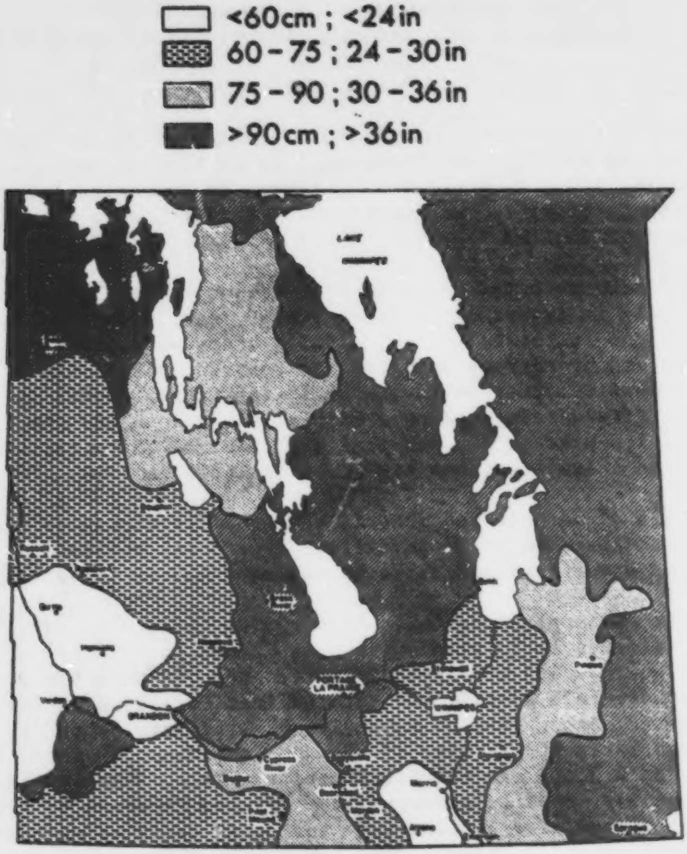
* Total Precipitation from August 27 to October 29, 1984

PRECIPITATION (SEP 10-OCT 29/84)

☐ <125mm ; <5in
▤ 125-150mm ; 5-6in
▒ 150-175mm ; 6-7in
▨ 175-200mm ; 7-8in
▩ >200mm ; >8in



DEPTH OF MOIST SOIL AS OF NOV 1/84



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Data provided by Atmospheric Environment Service

Note: This map is intended as a general guide. Because of local variability of soils and precipitation these values may not be right for your farm. For more accurate information you should examine your fields in the spring.

COPPER AND MOLYBDENUM NUTRITION OF FORAGE CROPS

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Introduction

Copper and molybdenum nutrition of forage crops has been investigated by the Soil Science Department as part of an Agroman project initiated in 1980. This paper is intended to summarize information on the effects of micro and macronutrient fertilizers on plant concentrations of Cu & Mo.

Field studies were conducted with the objectives of correcting Cu deficiency in livestock by increasing Cu and/or decreasing Mo concentrations in forage crops. Alfalfa crops were grown at Dauphin and Sifton and bromegrass was grown at Dauphin, Sifton and Stead. Two sites were selected on Edwards clay loam near Dauphin in 1980. The Sifton site was located on a Gilbert sandy loam and the Stead site on a mesic fen peat. Some physical and chemical characteristics of the soils at these locations are given in Table 1.

Details of methods and materials of the field studies have previously been described(*). Fertilizer treatments applied to alfalfa and bromegrass are shown in tables 2 and 3, respectively.

Copper was applied as $CuSO_4\ 5H_2O$ and Cu EDTA to investigate possible differences in plant uptake of Cu due to carrier. Copper from both sources was dissolved in water, sprayed onto the soil and incorporated before seeding to test the feasibility of increasing forage copper concentrations by applying fertilizer copper at relatively high rates at the time of stand establishment. These treatments are shown as 2,3,4,5 and 6 for both crops. Relatively low rates of copper were also applied as annual top-dressed treatments (8,9 and 10). The top-dressings were applied each spring as early as possible. Foliar treatments (11 and 12) were applied in only one year to alfalfa as serious leaf burn resulted, but were continued on the bromegrass sites in 1980 and 1981.

Phosphorus treatments of 0 kg P_2O_5/ha, 150 kg P_2O_5/ha as 11-55-0 and 75 kg P_2O_5/ha as 10-34-0 (treatments 13, 14 and 15, respectively) were applied annually to alfalfa to investigate concerns that high levels of fertilizer P may increase the availability to or uptake of soil molybdenum by forage crops. Applications of 0 and 300 kg N/ha as 34-0-0 (treatments 14 and 15, respectively) were applied to bromegrass to ascertain if plant molybdenum concentrations could be decreased as the result of biological dilution associated with a response in dry matter production to heavy N fertilization.

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* Tokarchuk, J.M., and L.A. Loewen-Rudgers. 1982. Copper and Molybdenum Nutrition of Forage Crops Proceedings of 25th Annual Manitoba Soil Science Meetings. pp. 108-122.

Table 1. Soil characteristics during the year of seeding for all sites

	Dauphin Spring 1980 poorly drained	 well drained	Sifton Spring 1981	Stead Fall 1981
NO_3-N, kg/ha 0–60 cm	88.9	140.0	21.4*	383***
P, kg/ha 0–15 cm	14.8	39.4	9.1	15.6
K, kg/ha 0–15 cm	708	1120	64.7	88.5
SO_4-S, kg/ha 0–60 cm	108	36.6	23.7*	215
Cu DTPA extractable, ppm 0–15 cm	2.6	2.3	0.34	0.95
Zn DTPA extractable, ppm 0–15 cm	9.1	10.6	0.59	7.1
Mn DTPA extractable, ppm 0–15 cm	15.8	13.3	1.8	5.8
Fe DTPA extractable, ppm 0–15 cm	29.4	33.8	3.6	420
pH 0–15 cm	7.6	7.0	7.7	5.6
Conductivity mmhos/cm	1.4	0.8	0.4	0.5
Organic matter %	7.7	7.3	3.3	80.0
$CaCO_3$	med.	low	med.	nil

*sampling depth was 0–30 cm

***samples taken in fall due to frozen soil in the spring

Table 2. Treatment list for bromegrass and Kentucky bluegrass

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Basal N applied at 150 kg N/ha (Dauphin, Sifton) and 100 kg N/ha (Stead) as 34-0-0. Basal P applied at 50 kg P_2O_5/ha (Dauphin, Sifton) and 75 kg P_2O_5/ha (Stead) as 11-55-0. Basal K applied at 100 kg K_2O/ha (Sifton, Stead) as 0-0-62. These were incorporated before seeding unless otherwise specified and surface broadcast annually thereafter.

1.	0 kg Cu/ha	
2.	25 kg Cu/ha ($CuSO_4$-soln)	
3.	100 kg Cu/ha ($CuSO_4$-soln)	
4.	25 kg Cu/ha ($CuSO_4$-granular)	incorporated before seeding
5.	5 kg Cu/ha (Cu EDTA-soln)	
6.	20 kg Cu/ha (Cu EDTA-soln)	
7.	25 kg Zn/ha ($ZnSO_4$-soln)	
8.	1 kg Cu/ha (Cu EDTA-soln)	
9.	5 kg Cu/ha (Cu EDTA-soln)	top-dressed annually
10.	5 kg Cu/ha ($CuSO_4$-soln)	
11.	2 x 0.5 kg Cu/ha ($CuSO_4$-soln)	foliar spray*
12.	2 x 0.05 kg Cu/ha (EDTA-soln)	
13.	0 P_2O_2/ha	
14.	No N	
15.	300 kg N/ha	top-dressed annually
16.	1 kg Cu/ha (Cu EDTA-soln)	
17.	5 kg Cu/ha (Cu EDTA-soln)	Dauphin only-incorporated before reseeding
18.	5 kg Cu/ha (Cu SO_4-soln)	

*Foliar spraying was conducted at Dauphin in 1980 and 1981, and at Sifton and Stead in 1981

Table 3. Treatment list for alfalfa

Basal P applied at 75 kg P_2O_5/ha as 11-55-0. Basal K applied at 100 kg K_2O/ha as 0-0-62 at Sifton only. These were incorporated before seeding unless otherwise specified and surface broadcast annually thereafter.

1.	0 kg Cu/ha	incorporated before seeding
2.	25 kg Cu/ha ($CuSO_4$-soln)	
3.	100 kg Cu/ha ($CuSO_4$-soln)	
4.	25 kg Cu/ha ($CuSO_4$-granular)	
5.	5 kg Cu/ha (Cu EDTA-soln)	
6.	20 kg Cu/ha (Cu EDTA-soln) Sifton Only	
7.	25 kg Zn/ha ($ZnSO_4$-soln)	
8.	1 kg Cu/ha (Cu EDTA-soln)	top-dressed annually
9.	5 kg Cu/ha (Cu EDTA-soln)	
10.	5 kg Cu/ha ($CuSO_4$-soln)	
11.	2 x 0.5 kg Cu/ha ($CuSO_4$-soln)	foliar spray*
12.	2 x 0.05 kg Cu/ha (Cu-EDTA-soln)	
13.	0 P_2O_5/ha	top-dressed annually
14.	150 kg P_2O_5/ha as 11-55-0	
15.	75 kg P_2O_5/ha as 10-34-0	

*Foliar spraying was conducted at Dauphin in 1980 and 1981, and at Sifton in 1981.

Basal treatments of N, P and K were made to both crops except when otherwise stated in treatment descriptions.

Results and Discussion

To facilitate reporting of results in this paper data from field study was averaged over the term of the experiment.

Table 4 shows the average Cu concentrations in alfalfa fertilized with copper at Dauphin and Sifton. At Dauphin where plant available soil copper was high (2.6 ppm DTPA extractable Cu), alfalfa copper concentrations ranged from 7.4 to 17.0 ppm. For alfalfa grown at Sifton (0.34 ppm DTPA extractable Cu) tissue copper concentrations ranged from 4.0 to 16.1 ppm. Where no copper fertilizer was applied at Dauphin, copper concentrations in the untreated plots contained 7.6 ppm, which would be considered adequate for normal plant growth. When copper was applied to the soil as $CuSO_4$ $5H_2O$ before seeding copper concentrations did increase slightly to 8.2 and 8.7 ppm Cu when 25 and 100 kg Cu/ha were applied. However, when the magnitude of response and the amount of copper required are considered, it is apparent that this method would not be practical for increasing copper concentrations in forage at either site. It should be noted, however, that neither site was critically low in soil copper. At worst the Sifton soil appeared to be marginal in plant available copper. Incorporating copper as Cu EDTA did not appear to be as effective in increasing copper concentrations in alfalfa as Cu SO_4 $5H_2O$. Forage copper concentrations increased only slightly from 7.6 to 8.0 and 4.0 to 6.0 at Dauphin and Stead, respectively, when 5 kg Cu/ha as Cu EDTA were applied.

Annual spring top-dressing treatments of copper appeared to have the most influence on alfalfa copper concentrations. Rates of 1 and 5 kg Cu/ha as Cu EDTA and 5 kg Cu/ha as $CuSO_4$ $5H_2O$ were applied. One kg Cu/ha as Cu EDTA raised Cu concentrations from 7.6 to 8.2 and 4.0 and 6.0 ppm at Dauphin and Sifton, respectively. Plant copper concentrations were increased by both carriers at the 5 kg Cu/ha rate, but $CuSO_4$ $5H_2O$ appeared to be slightly more effective at both sites.

Copper concentrations in bromegrass from the field locations are shown in table 5. As noted with alfalfa, Cu concentrations in the grass were adequate at Dauphin, but marginal at Sifton, and likely deficient at Stead. Critical copper concentrations for bromegrass were not found in the literature, but it would likely be safe to assume that the concentrations of 7.3 and 7.6 ppm Cu found in bromegrass at Dauphin P.D. and W.D., respectively would be adequate for good plant growth. However at Sifton and Stead, where bromegrass Cu concentrations were 3.8 and 2.7 ppm, respectively, one may be concerned with copper deficiency in the plant.

At Dauphin pre-seeding soil incorporated copper from either carrier resulted in only slight increases in bromegrass copper concentrations. When as much as 100 kg Cu/ha as $CuSO_4$ $5H_2O$ was applied plant Cu concentrations were only increased by 1-2 ppm. When 5 and 20 kg Cu/ha as Cu EDTA were applied in a similar manner Cu concentrations in bromegrass were increased by approximately the same amount as when $CuSO_4$ $5H_2O$ was used. Pre-planting soil incorporation of Cu fertilizer at Sifton and Stead resulted in greater increases in Cu concentrations, reflecting the lower amounts of plant available Cu in those soils. Incorporation of 25 and 100 kg Cu/ha as Cu SO_4 $5H_2O$ were quite effective and increased bromegrass Cu concentrations to 7.6 and 8.6, respectively, at Sifton and 10.2 and 10.9, respectively at Stead. At both Stead and Sifton incorporating 5 and 20 kg Cu/ha as Cu EDTA was slightly less effective in increasing plant Cu concentrations than $CuSO_4$ $5H_2O$ was.

Applying smaller amounts of Cu fertilizer as an annual top-dressing to bromegrass was the most effective method of supplying Cu, especially when 5 kg Cu/ha as either $CuSO_4$ $5H_2O$ or Cu EDTA were used. In particular 5 kg Cu/ha as $CuSO_4$ $5H_2O$ appeared to increase plant Cu concentrations the most.

Foliar applications which were conducted on bromegrass plots early in the study had little influence on bromegrass Cu concentrations at Dauphin and Sifton and were discontinued after 1981. However, at Stead where plant available soil Cu was the lowest, foliar applications of 1 kg Cu/ha as $CuSO_4$ $5H_2O$ and 0.1 kg Cu/ha as Cu EDTA did improve Cu concentrations, but to a lesser extent than the incorporated treatments did.

It was previously noted that top-dressing treatments resulted in the largest increases in forage Cu content of all the methods employed. When the data is divided into first and second harvest for each crop it is apparent that most of the influence of these treatments upon plant Cu content occured at first harvest, and very little at second harvest. At both Dauphin and Sifton greater increases in Cu concentration (table 6) resulted from the application of 5 kg Cu/ha as $CuSO_4$ $5H_2O$ or Cu EDTA. Although plant Cu concentrations

Table 4. Concentration of Copper in Alfalfa Tissue as Influenced by Copper Fertilization (early bloom stage, ppm)

Treatment	Location	
	Dauphin	Sifton
1	7.6	4.0
2	8.2	6.9
3	8.7	7.5
4	8.0	6.7
5	8.0	6.0
6	-	3.0
7	8.0	2.7
8	8.2	6.0
9	13.4	10.0
10	17.0	16.1
11	8.0	3.5
12	7.4	3.5

Table 5. Concentration of Copper in Bromegrass Tissue As Influenced by Copper Fertilization (early heading stage, ppm)

Treatment	Location			
	Dauphin P.D.	Dauphin W.D.	Sifton	Stead
1	7.3	7.6	3.8	2.7
2	8.1	8.8	7.6	10.2
3	8.2	9.8	8.6	10.9
4	7.6	9.9	5.6	8.3
5	8.2	9.3	6.7	7.9
6	7.3	10.4	4.0	11.5
7	7.2	8.4	4.8	3.0
8	7.3	10.4	4.0	11.5
9	8.1	10.4	6.1	17.1
10	15.8	12.0	7.5	27.0
11	7.5	9.0	4.1	6.6
12	8.1	8.6	3.8	5.1
16	8.1	8.6	3.8	5.1
17	7.7	9.3		
18	7.5	8.4		

Table 6. Effect of Top-dressed Cu on Cu in Alfalfa Tissue

		Rate and Type of Top-dressed Cu			
	Harvest	Check	1 Cu (EDTA)	5 Cu (EDTA)	5 Cu (SO_4)
Dauphin	1	7.8	9.2	23.0	16.9
	2	7.3	8.8	8.1	8.3
Sifton	1	3.6	6.4	10.9	21.8
	2	4.7	5.3	8.3	4.8

remained relatively high at second harvest it is apparent that the effect of the top-dressing treatment had been substantially diminished. Although results were similar when 1 kg Cu/ha as Cu EDTA was top-dressed, the magnitude of increase in plant Cu concentration was much smaller, likely due to the reduction in amount of Cu applied.

For bromegrass the effect of top-dressing Cu was not as clearly divided between harvests (table 7) at the Dauphin sties. At the Dauphin W.D. site little increase in Cu concentration was observed in any of the top-dressed treatments, and second harvest plant Cu concentration were slightly higher than at first harvest. On the Dauphin PD site first harvest bromegrass Cu concentrations were slightly higher than at second harvest, but not to the same extent as was observed with alfalfa. Again, the lack of response of bromegrass to Cu fertilizer was likely a reflection of the relatively high plant availability of soil Cu at the Dauphin sites. In addition, it may be likely that bromegrass is less responsive to Cu applied to the foilage (as a portion of these treatments were) than a broadleaf crop such as alfalfa.

At the Stead and Sifton sites top-dressing Cu was effective in increasing Cu concentrations in bromegrass, but again more so at the first than second harvest. Tissue Cu concentrations in the first harvest increased from 3.2 to 7.0 and 9.1 ppm when 5 kg Cu/ha as Cu EDTA and $CuSO_4$ $5H_2O$, respectively was applied at Sifton, and from 2.3 to 21.0 and 36.4 ppm when 5 kg Cu/ha as Cu EDTA and $CuSO_4$ $5H_2O$, respectively at Stead. A slight advantage was apparent in using $CuSO_4$ $5H_2O$ as the Cu source for these treatments.

Average concentrations of molybdenum found in alfalfa at Dauphin and Sifton are shown in table 8. In general Mo concentrations in alfalfa in excess of 5 ppm are considered high with respect to animal nutrition. In such circumstances one would be concerned about the occurance of molybdenosis in animals consuming the forage. In contrast, concentrations of several hundred ppm Mo are required to produce toxicity symptoms in plants. Considering the Mo concentrations at these two sites, one would be concerned about the occurance of molybdenosis at Dauphin where Mo concentrations ranged from 6.3 to 7.1 ppm, but not at Sifton were Mo in alfalfa was between 1.1 and 1.5 ppm.

Treatments of 0, 150 and 75 kg P_2O_5/ha (treatments 13, 14 and 15, respectively were applied annually to alfalfa to determine if applying high rates of P resulted in higher molybdenum availability to forage crops. Molybdenum concentrations were not influence by phosphorus treatments at either site.

With regard to animal nutrition it is desirable to maintain a Cu:MO ratio of 3 or 4:1 in forage if molybdenosis in livestock is to be avoided. Because of the high molybdenum concentration in alfalfa at Dauphin Cu:Mo ratios were well below the desired level ranging from 1.1:1 to 1.8:1 (table 9), (excluding treatments where Cu was top-dressed). At Sifton Cu:Mo ratios were satisfactory and did not fall below 3:1 in any treatment where Cu was either incorporated before seeding or top-dressed annually (table 9). Where Cu:Mo ratios did fall below 3:1 at Sifton, it was likely a reflection of very low Cu concentrations as plant Mo concentrations were quite low at this site.

Table 7. Effect of Top-dressed Cu on Cu in Bromegrass Tissue

	Harvest	Rate and Type of Top-dressed Cu			
		Check	1 Cu (EDTA)	5 Cu (EDTA)	5 Cu(SO_4)
Dauphin WD	1	8.5	7.9	8.5	7.0
	2	8.3	9.8	10.2	9.8
Dauphin PD	1	7.5	8.4	8.7	9.2
	2	7.1	7.4	6.6	5.7
Sifton	1	3.2	5.5	7.0	9.1
	2	5.0	5.8	4.4	4.4
Stead	1	2.3	11.3	21.0	36.7
	2	3.5	6.5	9.4	7.8

Table 8. Mo Concentrations in Alfalfa (early bloom, ppm)

Treatment	Location	
	Dauphin	Sifton
1	6.7	1.2
2	6.4	1.1
3	6.3	1.1
4	6.9	1.2
5	6.9	1.4
6	-	1.4
7	7.1	1.4
8	7.0	1.4
9	6.8	1.4
10	6.9	1.3
11	6.8	1.3
12	6.6	1.3
13	7.2	1.5
14	7.1	1.4
15	7.0	1.5

In contrast, both Cu and Mo concentrations were high at Dauphin, and Cu:Mo ratios were high due to the elevated Mo levels in the forage.

Molybdenum concentrations in bromegrass (table 10) were generally lower than those observed in alfalfa. Suprisingly, the bromegrass Mo concentrations at the Dauphin WD site were higher than those observed at the Dauphin PD site. From the literature it was thought that poor drainage would increase the availability or uptake of molybdenum, resulting in higher Mo concentration in plants at the PD site than at the WD site.

A rate of 300 kg N/ha was applied to bromegrass to determine if it was possible to dilute Mo in the plant by increasing dry matter production. When 300 kg N/ha was applied plant Mo concentrations in bromegrass at all sites were not reduced relative to when no nitrogen was applied.

Ratios of Cu:Mo in bromegrass (table 11) were well above 3:1 at the Dauphin PD, Sifton and Stead sites, and would not likely have caused molybdenosis to occur in livestock. At these sites Mo concentrations were low enough that high Cu:Mo ratios were not suprising.

Little work has been done to determine the residual value of Cu fertilizer in years after it has been applied. Although it was not the intention of this study to examine residual effects of Cu fertilizer specifically, the nature of the treatments did afford an apportunity to consider this question. For this purpose only data from the Cu responsive sites (Stead and Sifton), and the treatments where Cu was applied has been selected.

Copper was applied to the soil before seeding of alfalfa in 1981. When 100 kg Cu/ha as $CuSO_4$ $5H_2O$ was applied Cu concentrations were increased by 2.6 ppm and 5.1 ppm in 1982 and 1983, respectively (table 12). When 25 kg Cu/ha from the same source, as a solution or granular broadcast Cu was applied, concentrations were approximately 2 and 3 ppm higher than when no Cu was applied in 1982 and 1983, respectively. Although rates of Cu were lower when Cu EDTA was applied, this carrier was thought to be a more efficient source of Cu than the sulphate source. However, when 5 and 20 kg Cu/ha were applied, alfalfa Cu concentrations were lower than when 25 kg Cu/ha as $CuSO_4$ $5H_2O$ had been applied.

The residual effect of copper applied to bromegrass at Sifton and Stead are shown in tables 13 and 14, respectively. Over the 3 year period Cu concentrations were maintained at acceptable levels by the $CuSO_4$ $5H_2O$ treatments at both sites. When Cu EDTA was the carrier bromegrass Cu concentrations were slightly lower but acceptable after one year, but began to decline at Sifton 2 years after application. Initially little difference was detected between the carriers, but in 1983 a slight superiority was noted in favour of $CuSO_4$ $5H_2O$.

Table 9. Cu:Mo ratios in Alfalfa

Treatment	Location	
	Dauphin	Sifton
1	1.2	3.6
2	1.5	6.4
3	1.8	6.6
4	1.3	5.4
5	1.4	4.4
6	-	2.2
7	1.3	1.9
8	1.8	4.3
9	3.0	7.0
10	4.2	12.6
11	1.3	2.7
12	1.3	2.7
13	1.2	2.7
14	1.1	2.1
15	1.3	2.1

Table 10. Mo Concentration in Bromegrass (early heading, ppm)

Treatment	Location			
	Dauphin P.D.	Dauphin W.D.	Sifton	Stead
1	1.0	5.0	0.5	0.2
2	1.1	3.9	0.5	0.3
3	1.1	3.9	0.4	0.2
4	0.9	3.9	0.5	0.2
5	1.0	4.4	0.5	0.2
6	1.2	4.5	0.5	0.2
7	1.0	4.7	0.4	0.2
8	1.2	4.1	0.5	0.3
9	1.2	4.8	0.5	0.2
10	1.2	4.0	0.4	0.3
11	1.0	3.9	0.6	0.2
12	1.2	3.7	0.5	0.2
13	1.2	4.7	0.6	0.3
14	1.5	4.4	0.8	0.2
15	1.4	4.0	0.7	0.3
16	1.0	3.6		
17	0.8	3.9		
18	1.2	4.2		

Table 11. Cu:Mo Ratios in Bromegrass

Treatment	Location			
	Dauphin P.D.	Dauphin W.D.	Sifton	Stead
1	10.4	2.4	7.1	13.4
2	11.5	3.3	19.6	42.1
3	10.8	3.7	21.3	27.6
4	10.5	3.7	13.2	49.5
5	11.5	2.8	13.1	37.9
6	7.0	3.6	8.6	29.5
7	8.6	2.5	13.2	13.5
8	9.1	3.3	15.1	39.9
9	9.4	3.3	15.6	36.7
10	29.0	4.6	25.6	47.9
11	9.9	3.0	8.1	29.9
12	9.4	2.9	8.5	26.2
13	7.3	2.4	8.1	29.9
14	6.7	2.6	34.0	13.9
15	8.3	3.0	8.2	13.8
16	10.7	2.7		
17	11.8	2.9		
18	9.0	2.6		

Table 12. Residual Effect of Cu Applied to Alfalfa at Sifton in 1981

Treatment	Cu conc (ppm)	
	1982	1983
1 Control	3.9	3.4
2 25 kg Cu (SO_4) soln	5.5	7.4
3 100 kg Cu (SO_4) soln	6.5	8.5
4 25 kg Cu (SO_4) gran	5.0	7.2
5 5 kg Cu (EDTA) soln	4.2	6.1
6 20 kg Cu (EDTA) soln	2.7	3.1

Table 13. Residual Effect of Cu Applied to Bromegrass at Sifton in 1981

Treatment	Cu conc. (ppm)	
	1982	1983
1 Control	2.4	4.0
2 25 kg Cu/ha Cu (SO_4) soln	6.0	9.6
3 100 kg Cu/ha Cu (SO_4) soln	7.1	11.4
4 25 kg Cu/ha Cu (SO_4) gran	3.2	8.2
5 5 kg Cu/ha Cu (EDTA) soln	7.4	5.9
6 20 kg Cu/ha Cu (EDTA) soln	7.0	3.9

Table 14. Residual Effect of Cu Applied to Bromegrass at Stead in 1981

Treatment	Cu conc. (ppm)	
	1982	1983
1 Control	1.9	2.7
2 25 kg Cu/ha Cu (SO_4) soln	8.7	14.0
3 100 kg Cu/ha Cu (SO_4) soln	9.4	14.0
4 25 kg Cu/ha Cu (SO_4) soln	7.4	9.8
5 5 kg Cu/ha Cu (EDTA) soln	7.8	8.6
6 20 kg Cu/ha Cu (EDTA) soln	8.4	17.4

Summary and Conclusions

Field trials were conducted at Dauphin, Sifton and Stead to determine if methods of fertilizing forage could influence the concentrations of Cu and Mo in alfalfa and bromegrass. Copper was applied as $CuSO_4$ $5H_2O$ and Cu EDTA at various rates and by several methods to determine if Cu concentrations in forage could be increased. Variable rates of P and N were applied to alfalfa and bromegrass, respectively to determine if these macronutrients influenced the Mo concentrations in forage. Results of these investigations have been summarized in this paper.

It was found that soil incorporation of large amounts of Cu from either the $CuSO_4$ $5H_2O$ or Cu EDTA source before seeding had little effect on Cu concentrations in alfalfa and bromegrass at the Dauphin sites. At Sifton and Stead pre-seeding soil incorporation of Cu at high rates increased and maintained Cu concentrations in the forage at satisfactory levels through the duration of the study. A slight advantage was observed in favour of using $CuSO_4\ 5H_2O$ for the soil incorporated treatments. It was further noted that the incorporation of Cu into the soil before seeding was effective in increasing forage Cu concentrations only on soils which were marginal or deficient in plant available Cu. Where soil Cu was adequate for plant growth these treatments had little effect on plant Cu concentrations.

Annual top-dressing treatments of Cu were applied to alfalfa and bromegrass in the spring. Treatments were made as early as possible in the spring, but inevitably some regrowth would have occured by that time. As a result, a portion of the Cu applied in this manner would be similar to a foliar application. It was interesting to note that when Cu was applied at the 5 kg Cu/ha rate at this early stage of growth, leaf burn did not occur on alfalfa. However, leaves of alfalfa were damaged by much lower rates of Cu at a later stage of growth. It would appear that when Cu is applied early in the spring in this manner that alfalfa can tolerate considerably high rates of Cu than of early stages of growth.

Top-dressing Cu was the most effective method of increasing forage Cu concentrations of the methods considered. Applying 5 kg Cu/ha as either carrier increased forage Cu concentrations with most of the treatment effect occuring in the first harvest, and little in the second harvest.

Macronutrient treatments were also applied to forage to determine the effect of N and P on Mo concentrations of alfalfa and bromegrass. Molybdenum concentrations in alfalfa were not influenced by applying phosphorus fertilizers. From this data there appears to be little danger of increasing Mo concentrations in alfalfa to levels which may be harmful to livestock, by adding phosphorus fertilizer. In bromegrass Mo in the plant was not diluted through increased dry matter production when 300 kg N/ha was applied. It was concluded that macronutrient fertilization had little influence on Mo concentrations in forage.

COPPER FERTILIZATION OF WHEAT AND METHODS OF EVALUATING AVAILABILITY OF COPPER TO WHEAT GROWING ON MINERAL SOILS

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The copper content of most mineral soils in Manitoba is generally considered adequate for the production of wheat. Some soils, notably those of coarse texture and good drainage are suspected of being marginal in copper, however few responses to applied copper have been obtained. New interest in soil micronutrient supply has been generated in recent years, due to intensive crop production and interest in special crops. A study was therefore initiated to evaluate the copper status of mineral soils. The objectives specifically were to: 1. determine the effect of copper fertilization on yield and copper content of wheat growing on mineral soils; 2. evaluate chemical extractants for assessing the availability of soil copper; 3. mathematically relate extractable soil copper to yield, plant copper concentration, and copper uptake.

The study was conducted as an M.Sc. practicum by Mr. Kamwaga[1]. It consisted of two field experiments and two growth chamber experiments. Wheat (Triticum Aestivum Var. Columbus) was used as the test crop in both field experiments and the first growth chamber experiment. Soil copper extracting solutions used were DTPA, 0.1 MHCI, 1.0 M HCl, Na_2DP and Na_2 EDTA.

Field experiments were conducted in 1982 on a Gilbert S.L. near Sifton and an Almasippi LFS north of Haywood. In 1983 another experiment was placed on an Almasippi LFS south of Haywood. Copper concentrations of the soils at planting time (determined with DTPA) were 0.34, 0.42, and 0.26 PPM respectively. Application of copper did not significantly increase mid season or final harvest yields on these field sites, thus data is not included herein.

In a growth chamber experiment, wheat was grown on ten soils to study the effect of copper fertilization on yield, and copper uptake by the wheat. The experiment consisted of two treatments: 1. no copper, 2. copper at 38 mg Cu per pot (15 kg Cu per ha). Treatments were replicated three times. Copper was applied in treatment 2 using $CuCl_2.2H_2O$ mixed with the soil. All pots contained 5 kg of soil and received basal treatments of N, P, K, S mixed with the soil.

Soils were selected to provide a range of extractable copper, with some variation in soil pH and carbonate content (Table 1). Five extracting solutions were used to determine extractable copper (Table 2). The soil from Dauphin had the highest copper content which was not surprising because of the clay loam texture. All other soils contained considerably less copper. In general, 0.1 M HCl and DTPA extracted less copper than the other extractants, and 1.0 M HCl extracted the most.

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[1] Kamwaga, J.N. 1984. Copper fertilization of wheat and methods evaluating availability of copper to wheat growing on mineral soils. M.Sc. Thesis. Dept. Soil Science, The University of Manitoba.

Yields of wheat were increased by the application of copper on nine of the ten soils (Table 3). Yield increases were significant ($p = .05$) on six of the ten soils. Two of the soils, i.e. at Sandilands and Cowan, did not produce grain without the application of copper. Failure to set seed because of non viability of pollen is a recognized deficiency symptom of copper. Percent yield data is also shown in Table 3 and is calculated:

$$P.Y. = \frac{\text{Yield with no copper} \times 100}{\text{Yield with copper}}$$

The relationship between Percent Yield and soil copper extracted by the five extractants at planting time is shown in Table 4. Only 1.0 M HCl extractable copper could be significantly related to Percent Yield. This indicates that only a strong acid extractant was useful as a soil test for copper, under the conditions of this experiment. Weak acid (0.1 M HCl) extracted the least amount of copper and this may be due to the destruction of the acid by soil carbonates.

Relationships between percent yield and copper extracted from the soil at harvest time are shown in Table 5. The chelate extractant DTPA and strong acid extractant (1.0 M HCl) extracted copper that was significantly related to percent yield. Why DTPA extractable copper at harvest time should relate better to harvest index than DTPA extractable copper at planting time is not understood.

The copper content of wheat harvested at the boot stage was significantly increased by the application of copper on nine of the ten soils. Plants grown on the soil from Treherne had a slight but not significant increase in copper. The copper concentration of wheat produced on all soils, including the non-copper treated soils, was above the generally accepted 2.0 ppm critical copper concentration, thus increased copper uptake was likely luxury consumption. The copper concentration of the seed was increased by the application of copper on all soils, but significant increases ($p = .05$) were obtained on six of the ten soils. Two of the soils that produced no seed without copper fertilization, produced seed of high copper content when treated with copper.

The soil copper concentrations at which grain yields were increased can be determined from data in Tables 2 and 3, except for the weak acid extractant (0.1 M HCl). The amount of copper extracted by the weak acid was too low to be considered valid. Significant increases in grain yields due to copper application were obtained when soil copper concentration was less than: 1.7 ppm for 1 M HCl, 1.1 ppm for Na_2DP, 1.2 ppm for Na_2EDTA, and 0.2 ppm for DTPA. Significant increases in grain yields were not obtained when soil copper concentrations exceeded 2.2 ppm for 1.0 M HCl, 1.5 ppm for Na_2DP, 2.5 ppm for Na_2EDTA, and 0.4 ppm for DTPA. Soils with copper concentrations between these values produced inconsistent results when fertilized with copper.

A second growth chamber experiment was conducted to determine the optimum rate of copper application for wheat, and the effect on copper concentration in plant tissue and grain. Soil was obtained from the same field as Haywood A. in the previous study because it had shown good response to added copper. The copper content of this soil determined by DTPA extraction was 0.24 ppm. The experiment consisted of six treatments with three replicates. Wheat (Triticum Aestivum Var. Benito) was grown in pots containing 5 kg of soil. All pots received basal treatments of NPKS. Treatments consisted of rates of copper: 0, 2.5, 5.0, 10, 15, 25 of Cu/ha equivalent, applied as $CuCl_2.2H_2O$ and was mixed with the soil.

At the boot stage of plant growth, application of copper had no effect on dry matter yield (Table 7). The copper concentration of the tissue increased with increasing rate of copper applied, however a significant increase was obtained only at the rate of 25 kg Cu/ha. Total copper uptake followed the same trend as copper concentration. Grain yields were increased by application of 5, 10, and 15 kg Cu/ha, however a slight reduction from maximum occurred when 25 kg Cu/ha was applied (Table 8). Copper concentration of the grain and total copper uptake increased with increasing rates of copper application. The rate of increase was much greater than the rate of yield increase, indicating luxury consumption of copper by the plant.

In summary, data from this study indicates that:

1. Wheat grown in growth chambers is more responsive to application of copper than wheat grown on the same soil in the field. This may be due to reduced copper supply in pots caused by low soil volume. It may also be due to greater pressure on soil to provide copper when plants are growing prolifically in a growth chamber.

2. Chemical extractants were able to identify soils that were very low or very high in soil copper, in growth chamber studies. Some soils required copper at levels of soil copper considered to be marginal, and some did not. This was indicated with DTPA extractable copper at soil concentrations of 0.3 to 0.4 ppm.

3. Wheat tissue and grain copper concentrations can be increased by the application of copper. Increases in yield however did not occur simultaneously except on soils very low in extractable copper.

4. A strong acid extractant (1.0 M HCl) provided the best relationship between extractable copper and percent yield in these experiments. DTPA gave good correlation with soil copper at harvest time.

Table 1. Characteristics of soils used in growth chamber experiments.

Location	Soil Series	pH	Carbonate (%)
Poppleton	Poppleton L.F.S.	7.3	0.3
Sandilands	Sandilands F.S.	6.3	0.2
Haywood A.	Almasippi F.S.	7.0	0.2
Graysville	Almasippi L.F.S.	7.1	0.5
Sifton	Gilbert S.L.	7.4	7.3
Dauphin	Edwards C.L.	7.1	0.2
Treherne	Almasippi F.S.	6.8	0.4
Haywood B.	Almasippi F.S.	7.7	6.1
Steinbach	Pelan F.S.	7.4	0.3
Cowan	Spearhill L.S.	6.7	0

Table 2. Soil copper concentration determined by five extractants.

	Extractable Cu (ppm)				
	0.1 M HCl	1.0 M HCl	Na_2DP	Na_2EDTA	DTPA
Poppleton	0.2	2.4	1.5	2.5	0.3
Sandilands	0.2	0.3	0.6	1.0	0.1
Haywood A.	0.3	0.9	0.9	1.2	0.4
Graysville	0.1	1.1	1.1	2.1	0.3
Sifton	0.1	1.1	0.6	1.3	0.3
Dauphin	1.6	12.9	5.4	7.2	2.6
Treherne	0.1	1.7	1.0	1.2	0.3
Haywood B.	0.1	2.4	1.6	1.7	0.4
Steinbach	0.5	2.2	1.5	1.9	0.9
Cowan	0.1	0.6	0.7	0.8	0.1

Table 3. Effect of copper fertilization on yield of wheat.

	Mean Grain Yields gm/pot[1]		
Soil Location	No Cu added	38 mg Cu added	Percent Yield
Poppleton	13.9	17.7	79
Sandilands	0	20.7 *	0
Haywood A.	3.8	17.1 *	22
Graysville	3.9	20.4 *	19
Sifton	15.7	19.2 *	82
Dauphin	18.1	22.6	80
Treherne	13.3	17.1 *	78
Haywood B.	12.2	13.2	92
Steinbach	19.7	19.7	100
Cowan	0	21.4 *	0

[1] Mean of three replicates
*Means are significantly different at p = 0.5

Table 4. Relationship between percent yield and initial soil copper.

Extractant	Equation	F	R^2
DTPA	Y = 11.6 + 117.7 X	5.4	0.43
0.1 M HCl	Y = 39.3 + 69.3 X	0.4	0.05
1.0 M HCl	Y = -11.7 + 45.4 X	22.5	0.76 **
Na_2DP	Y = -19.0 + 67.7 X	5.21	0.43
Na_2EDTA	Y = - 3.2 + 36.5 X	2.3	0.24

Y = Percent Yield
X = Extractable copper in ppm
** = Significant at p = .01

Table 5. Relationship between percent yield and final soil copper.

Extractant	Equation	F	R^2
DTPA	Y = -86.0 + 659.1 X	10.1	0.59 *
0.1 M HCl	Y = 57.8 - 58.0 X	0.2	0.02
1.0 M HCl	Y = -23.6 + 57.4 X	9.7	0.58 *
Na_2DP	Y = 44.9 + 12.6 X	0.1	0.01
Na_2EDTA	Y = 43.2 + 9.3 X	0.1	0.01

Y = Percent Yield
X = Extractable copper in ppm
* = Significant at p = .05

Table 6. The effect of copper fertilizer on tissue copper concentration of wheat harvested at the boot stage, and seed.

Soil	Mean copper concentration (ppm)			
	Wheat at boot stage		Seed	
	No Cu	38 mg Cu/pot	No Cu	38 mg Cu/pot
Poppleton	4.2	7.8 **	1.4	5.6 *
Sandilands	2.7	8.6 **	-	6.5
Haywood A.	3.3	8.5 **	1.0	4.7 *
Graysville	2.5	7.3 **	0.5	3.8 *
Sifton	2.6	7.8 **	1.5	5.5 *
Dauphin	3.7	5.2 **	3.1	3.2
Treherne	3.7	4.7	1.2	2.5
Haywood B.	3.5	7.9 **	1.4	4.4 *
Steinbach	4.0	10.0 **	1.3	5.7 *
Cowan	3.8	6.5 **	-	5.1

Means followed by same letter within columns are not significantly different at: *p = .05; **p = .01

Table 7. The influence of copper fertilization on dry matter yield and copper concentration of wheat harvested at the boot stage.

Cu added (kg/ha)	Dry matter g/pot	Copper concentration (ppm)	Total copper Uptake mg/pot
0	4.4 a	6.3 b	27.6 b
2.5	4.5 a	6.3 b	28.7 b
5.0	4.2 a	6.8 b	28.8 b
10.0	4.2 a	7.5 b	31.5 b
15.0	4.5 a	7.5 b	33.9 b
25.0	4.5 a	9.9 a	42.7 a

Means followed by same letter within columns are not significantly different at p = .05

Table 8. The influence of copper fertilization on grain yields, grain copper concentration and total copper uptake of wheat at maturity.

Cu added (kg/ha)	Grain yield g/pot	Copper con-concentration (ppm)	Total copper uptake mg/pot
0	22.9 cb	2.4 c	94.0 c
2.5	22.7 c	3.7 cb	123.1 c
5.0	24.0 ab	5.0 b	162.5 b
10.0	24.2 a	4.7 b	173.6 ab
15.0	24.2 a	4.8 b	170.0 ab
25.0	23.6 abc	6.5 a	203.1 a

Means followed by the same letter within columns are not significantly different at p = .05

EFFECTS OF PHOSPHOROUS RATES ON ALFALFA SEED YIELDS

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Introduction:

While alfalfa seed production has been carried out in Manitoba for over 50 years it has only been in the last ten years that the production has intensified. In the past, alfalfa seed production was a by-product of the forage program intended for livestock feeding purposes. In years of good hay production, some of the hay stands would be left for seed. But over the years, seed production declined as many of the nesting sites of our natural pollinators were destroyed. Increasingly, Canada relied on imported supplies of seed alfalfa. This trend started to reverse itself about 10 years ago, following the introduction of the alfalfa Leafcutter bee, Megachile rotundata (Fabricius).

In April 1979, the Manitoba Alfalfa Seed Producers' Association, formerly known as the Manitoba Leafcutter Bee Association, began a five year Canada-Manitoba Agro-Man Project designed to develop and demonstrate improved agronomic practices for alfalfa seed production in Manitoba. Through producer inputs, three main areas of management were identified for activity under the Association's contract. They were:

a) Insect pest identification and control
b) Weed control in seedling and established alfalfa
c) Fertility requirements for optimum seed production

I will confine my remarks to this last area of concern in the trials that the Association put out to address this issue.

The growers were of the opinion that when they followed the soil test recommendations, particularly in respect to phosphorus recommendations, they observed no increase in seed production. To address this issue a trial was established in the fall of 1979 on an established seed field of Algonquin alfalfa near Arborg, Manitoba. The field tested very low for phosphorus (Table 1) and the soil test recommendation called for an application of 60 kilograms per hectare of phosphate. The treatment list is given in Table 2 with each plot measuring 30 feet by 250 feet to allow for combine harvesting.

The trial continued for three years until the plot was lost during the winter of 1982-83. The yields obtained are outlined in Table 3. There was remarkably little difference in yield over the three year period. The soil tests (Table 4) indicated that there was little build up of phosphorus in the soil except at the high rate of application. Plant tissue analysis (Table 5) showed no difference between the various treatments.

A second trial was initiated in the spring of 1980 at Teulon, Manitoba. The soil test indicated a low phosphorus level and the recommendation was for 56 kilograms per hectare of phosphorus prior to seeddown (Table 6). The trial was set up to compare various rates of phosphorus and also broadcast versus sideband application (Table 7). Once again the plot size was large, 10 meters by 75 meters, to allow for combine harvesting.

Unfortunately, only two crops were harvested before the plot area was lost to severe winterkilling. Table 8 shows the yields that were obtained and while there is no real difference, numerically the two check plots yielded higher than any of the treatments. Soil and tissue tests were not obtained in 1981. The 1982 tests (Table 9) indicated that there were some slight soil buildup from the broadcast applications but the tissue tests indicated little difference in phosphate levels between the various treatments.

Summary:

The evaluation trials conducted by the Manitoba Alfalfa Seed Producers' Association have tended to reinforce the growers' perception that phosphate fertilizers are not required for alfalfa seed production. In view of the well documented correlation between phosphorus and alfalfa herbage production, it would seem that there is a need for more detailed research into the roll that phosphorus plays in alfalfa seed production in Manitoba.

Table 1. Soil Characteristics NE28-22-3E
Manitoba Soil Testing Lab, Fall 1979

	Soil Depth In cm	
	0 - 15	15 - 60
Soil Type And Texture	Arborg Clay	
pH	7.3	
Carbonate Content	Medium	High
Nitrate Nitrogen	10 kg/ha	10 kg/ha
Phosphorus	8 kg/ha	-
Potassium	752 kg/ha	-
Sulphate Sulphur	12 kg/ha	63 kg/ha

Table 2.

	Treatments	
1	0-60-0-0	Spring Applied
2	Check	
3	0-30-0-0	Fall Applied
4	Check	
5	0-60-0-0	Fall Applied
6	0-120-0-0	Fall Applied
7	Check	
8	0-60-60-0	Fall Applied
9	0-0-60-0	Fall Applied
10	Check	
11	0-60-0-30	Fall Applied
12	100-60-60-0	Fall Applied
13	Check	

- Phosphate source was ammonium phosphate.

Table 3.

Plot Yields

		kg/ha Of Clean Seed			
Treatment		1980	1981	1982*	3 Year Average
1	0-60-0 S	724	594	61	460
2	Check	715	766	39	507
3	0-30-0 F	666	813	39	506
4	Check	715	791	46	517
5	0-60-0 F	697	742	29	489
6	0-120-0 F	711	821	36	523
7	Check	671	774	58	501
8	0-60-60 F	711	726	41	493
9	0-0-60 F	618	671	46	445
10	Check	675	742	90	502
11	0-60-0-20 F	591	766	49	469
12	100-60-60 F	520	805	51	459
13	Check	541	671	107	440

* Production was very poor primarily due to winter injury in 81-82 and an early frost (August/82) before the seed crop would mature fully.

- Field yielded 672 kg/ha in 1979.

Table 4. Soil Test Phosphorus Levels
Spring '79 Total Plot Area 23 kg/ha
Fall '79 Total Plot Area 8 kg/ha.

Treatment		Phosphorus Level kg/ha	
		*Spring 1981	Fall 1981
1	0-60-0 Spring	22	19
2 + 4	Check	12	14
3	0-30-0 Fall	21	22
5	0-60-0 Fall	13	36
6	0-120-0 Fall	37	107+
7 + 10	Check	8	23
8	0-60-60 Fall	11	33
9	0-0-60 Fall	11	8
11	0-60-0-30 Fall	12	28
12	100-60-60 Fall	11	15
13	Check	8	8

* Due to early snow fall, sampling and fertilizing scheduled for fall of 1980 was conducted in April 1981.

Table 5. Plant Tissue Analysis.

Treatment		% Phosphorus Content	
		July 14/80 Flowering	June 30/82 Early Flowering
1	0-60-0 S	0.22 (Marginal)	0.28 (Sufficient)
2 + 4	Check	0.23	0.28
3	0-30-0 F	0.22	0.28
5	0-60-0 F	0.20	0.27
6	0-120-0 F	0.20	0.27
7 + 10	Check	0.20	0.25
8	0-60-60 F	0.21	0.27
9	0-0-60 F	0.24	0.28
11	0-60-0-30	0.18 (Low)	0.28
12	100-60-60	0.21	0.26
13	Check	0.18	-

Table 6. Soil Characteristics SW11-16-2E
Manitoba Soil Test Lab May/80

Soil Type	Lakeland	Clay Loam
Carbonate Content	High	High
pH	7.9	
Salinity (ms/cm)	0.6	0.7
Nitrate Nitrogen	78 kg/ha	87 kg/ha
Phosphorus	14 kg/ha	
Potassium	381 kg/ha	
Sulphate Sulphur	44 kg/ha	134 kg/ha
Soil Test Recommendation	0-56-0-0	

Table 7. Plot Treatments

	At Seeding	Fall '81	Fall '82*
1	0-134-0 Broadcast & Incorporated	0-112-0 B	0-112-0 B
2	Check	-	-
3	0-280-0 Broadcast & Incorporated	-	-
4	0-112-0 Sideband	-	-
5	Check	-	-
6	0-112-0 Sideband	0-112-0 B	0-112-0 B

* Plots not harvested in 1983 due to winter killing in 1982-83.

Table 8. Plot Yields

Treatment		kg/ha Of Clean Seed		
		1981	1982	2 Year Average
1	B-B-B	402	186	294
2	Check	528	190	259
3	B - -	489	136	312
4	S - B	514	185	350
5	Check	521	211	366
6	S-B-B	431	128	280

Plots were not harvested in 1983 due to severe winterkilling in 1982-83.

Table 9.

Phosphorus Levels
Spring 1980 Soil Test 14 kg/ha

Treatment		Soil Test October 1982	Tissue Test June 30 1982 Early Flower
1	B-B-B	19 kg/ha	0.29% (Suff.)
2	Check	5 kg/ha	0.27%
3	B - -	18 kg/ha	0.32%
4	S - B	6 kg/ha	0.30%
5	Check	4 kg/ha	0.24% (Mar.)
6	S-B-B	5 kg/ha	0.26%

THE MEASUREMENT OF NITRATE AND NITRITE IN SOILS BY REVERSE PHASE HPLC

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ABSTRACT

Nitrate, nitrite, and phosphate can be determined by reverse phase HPLC, using 1:1 methanol-water at pH 3.0 as the mobile phase and UV detection at 214 nm. At a flow rate of 1.0 mL/min, these anions elute within 5 min. A comparison of the mobile phases 1:1 methanol-water and Low UV PIC A reagent indicates that 1:1 methanol-water yields 10 fold greater sensitivity to nitrate and 2 fold less to nitrite. HPLC analysis of nitrate in 3 soils is compared with the phenoldisulfonic acid and hydrazine sulfate methods of nitrate analysis. The use of various extractants for these anions in soils is discussed.

INTRODUCTION

The importance of determining nitrate and nitrite levels in agricultural soils is illustrated by the numerous methods of analysis for these ions (Keeny and Nelson 1982). In Manitoba, the phenoldisulfonic acid and hydrazine sulfate methods are the two most widely used nitrate analysis methods. The Griess-Ilosvay method can be used for nitrite analysis. A technique not commonly employed for soil nitrate and nitrite anaylsis is high performance liquid chromatography (HPLC).

Ion chromatography HPLC for the analysis of inorganic ions was first reported by Small _et al_. (1975). Recently, reverse phase column packings have also been shown to be effective for the separation of inorganic ions. Molnar _et al_. (1980) used a LiChrosorb RP-18 column with a mobile phase of 0.002 M tetrabutylammonium hydroxide plus 0.05 M phosphate buffer (pH 6.7) to separate various anions. For the separation of nitrate and nitrite in water samples, Kok _et al_. (1983) used a Radial-Pak C-18 μBondapak column with PIC A _UV_ grade reagent as the mobile phase. Vilsmeier (1984) used 1 mM tetrabutylammonium hydrogen sulfate and 25 mM sodium orthophosphate (pH 6.7) to separate nitrate, nitrite and dicyandiamid.

We have found that nitrate and nitrite may be separated by a RP-18 column 1:1 methanol-water as the mobile phase. Nitrate can be quantitatively extracted from different soils with water. This study examines the separation of nitrate, nitrite, and phosphate using 1:1 methanol-water at pH 3.0 as the mobile phase. The phenoldisulphonic acid (Bremner 1965), hydrazine sulfate, and HPLC methods are compared for their effectiveness of analyzing nitrate added to three different soils. The efficacies of water, 1:1 methanol-water, sodium bicarbonate, and silver sulfate-copper sulfate as soil nitrate extractants are compared.

MATERIALS AND METHODS

HPLC analysis was performed using a Waters Scientific (Mississuaga, Ont.) Model M45 pump, Model U6K injector, and Model 441 UV detector. The detector was modified with the optional kit to allow detection at 214 nm. The output was monitored with a Omniscribe strip chart recorder. A 4 mm I.D. x 250 mm 10 micron LiChrosorb RP-18 column (Merck) was operated at ambient temperature (ca. 24° C).

HPLC grade methanol and isopropyl alcohol were obtained from Caledon Laboratories (Georgetown, Ontario). Low UV PIC A (tetrabutylammonium hydrogen sulfate) (Waters Scientific) was prepared by dissolving the contents of the vial in one litre of distilled water. Glass distilled water was used for all preparations. All reagents were the highest purity available. For the preparation of the mobile phases or the standards, the solvents and water were filtered with a 0.45 micron Millipore filter and degassed. The pH was adjusted with 1 M sulphuric acid unless otherwise noted. Potassium hydrogen phthalate buffer (pH 3.0) was made by adding 22.4 mL 0.1 M HCl to 50 mL 0.1 M potassium hydrogen phthalate.

The characteristics of the three Manitoba soils used in this study are given in Table 1. All three soils had a pH of 7.9. Salinity was 0.2 mmhos/cm.

Table 1: Characteristics of soils used in the study.

NAME	TYPE	% SAND	% SILT	% CLAY	% OM	NITRATE (ppm)	PHOSPHATE (ppm)
P1	sand	89	5	11	2.3	1.0	2.8
P2	loam	44	37	19	2.5	26.0	4.0
T1	clay	17	28	55	7.2	117.0	58.8

To study the efficiency of nitrate recovery, 2 g (HPLC method), 2.5 g (hydrazine sulfate method) or 5 g (phenoldisulfonic acid method) of soil was added to a 250 mL Erlenmyer flask. The required amount of nitrate was added from a

50 mg/L potassium nitrate stock solution and the total amount of liquid in the flask was made up to 5 mL with distilled water. The soil solution was then shaken in a water bath (Fisher Model 129) at 25° for 30 min and placed in a 90° oven for 24 h, to evaporate the water.

For HPLC analysis, 6 mL of water or 1:1 methanol-water was then added to the flask. After shaking for 45 min, the soil solution was filtered with #5 Whatman filter paper. One millilitre of the filtered solution was then filtered with a 0.45 micron disposable syringe filter (Micron Separations Inc., N.Y.). Normally, less than 8 µl of this filtrate was directly injected into the HPLC for analysis at 214 nm.

For the phenoldisulfonic acid method the soil was extracted with 25 mL of nitrate-extracting solution. This solution was prepared by mixing 20 mL of 1 M copper sulfate and 100 mL of 0.6% silver sulfate and diluting to 1 L with distilled water. The soil and extracting solution were shaken for 30 min, during which time 0.16 g of calcium hydroxide and 0.5 g of magnesium carbonate were also added. The nitrate in this extract was then determined by a modified phenoldisulfonic acid method (Bremner 1965). For this procedure, 5.0 mL of the soil extract was pipetted into a 50 mL beaker and evaporated to dryness at 95°. The concentration of the nitrate was determined with a Bausch and Lomb Spectronic 710 at 415 nm, using a 10 cm light path.

For the hydrazine sulfate method, the soil was extracted with 0.5 M sodium bicarbonate for 30 min and analyzed with a Tecnicon Auto Analyzer.

RESULTS AND DISCUSSIONS

Separation of Nitrate, Nitrite, and Phosphate

Distilled water at pH > 5.5 and flow rates of 0.5 to 1.0 mL/min was ineffective at separating nitrate and nitrite. As the pH was lowered to pH 2.9, the separation between nitrate and nitrite increased, with nitrate eluting first. The choice of the acidifing agent, e.g., HCl, acetic acid, or sulfuric acid, was important in determining the elution characteristics. Acidification to pH 2.9 with HCl resulted in slightly longer retention of nitrate and nitrite, reduced sensitivity, and a noiser baseline, whereas, the use of sulfuric acid produced a cleaner and more sensitive chromatographic response. However, phosphate was found to have the same retention time as nitrate. Carbonate, phosphate, and hydrogen phthalate buffers, methanol, and isopropyl alcohol were also examined as mobile phases for the separation of nitrate, nitrite, and phosphate.

A 1:1 mixture of methanol and water (pH 2.9) was found to result in the best separation of phosphate from the nitrate (Figure 1a). The high concentration of phosphate needed to elicit a detector response indicates that phosphate would be essentially non-detectable at concentrations normally found in our soils (< 100 ppm). A concentration of 2000 mg/L was required to confidently determine the retention time for phosphate. At this high concentration, it was found that column performance deteriorated with phosphate use, necessitating column cleaning.

Low UV PIC A was effective at separating nitrate and nitrite (Figure 1b). In contrast to the other mobile phases studied, Low UV PIC A eluted nitrite first. Phosphate concentrations of up to 2000 mg/L were not detectable. Table 2 shows the retention times of nitrate, nitrite, and phosphate.

Table 2: Retention times (min) of nitrate, nitrite, and phosphate with 1:1 methanol-water and Low UV PIC A.

MOBILE PHASE	RETENTION TIMES FOR NITRATE	 NITRITE	 PHOSPHATE
1:1 MeOH-Water	1.62	4.90	2.57
Low UV PIC A	5.08	2.92	n.d

n.d. - not detectable

Response for Nitrate and Nitrite

An absorbance of 0.001 was obtained for approximately 0.05 mg/L (ppm) nitrate and 2.5 mg/L nitrite, utilizing 1:1 methanol-water (pH 2.9). With PIC A, approximately 1.0 mg/L nitrate and 0.6 mg/L nitrite were required to produced absorbances of 0.001.

The nitrate standard curve produced with 1:1 methanol-water is linear from 0.1 to 80 mg/L (Figure 2), while the nitrite standard curve is linear from 2.5 to 400 mg/L (Figure 3). Nitrate concentrations greater than 80 mg/L result in decreasing non-linear responses. Nitrite concentrations > 400 mg/L were not analyzed. With PIC A, the nitrate standard curves were linear from 0.75 to 100 mg/L (Figure 2) and the nitrite curves were linear from 0.75 to 175 mg/L (Figure 3). The 1:1 methanol-water system provides an approximate 10 times greater sensitivity for nitrate than the PIC A. In contrast, the PIC A is twice as sensitve to nitrite. Using the same type of column with PIC A reagent and UV detection, Kok _et al_. (1983) calculated the detection limit to be 0.1 mg/L for nitrate and nitrite.

Extracted soil samples analyzed with 1:1 methanol-water revealed only two peaks of major concern (Figure 4). The first and largest peak was the nitrate peak. The second smaller peak is currently unknown. The resolution of the peaks was better using 1:1 methanol-water (Figure 4a) rather than water (Figure 4b) as a soil extracting solution. Visually, the water extracts showed more yellow coloration than the 1:1 methanol-water extracts. When PIC A was used as the mobile phase (Figure 4c) only a nitrate peak appeared although a noisier baseline was evident. No substantial difference in nitrate recoveries was noted between the use of 1:1 methanol-water or PIC A as the HPLC mobile phase. With PIC A, the use of 1:1 methanol-water as a soil extractant resulted in another small peak eluting at approximately the void volume which appeared to be due to the methanol in the extracting solution.

Comparison of nitrate analysis methods

In the sand (P1) and loam (P2) soils there was little difference in the amount of nitrate recovered when assayed by the phenoldisulfonic acid, hydrazine sulfate, or HPLC methods (Figure 5a and 5b). The variation between the methods can be attributed more to the variation within the samples of a method rather than between the methods. For the clay soil (T1), the phenoldisulphonic acid consistently gave lower recovery values, perhaps due to the high organic matter level (7.2%) of this soil (Figure 5c). The HPLC method compares favorably with or is better than the phenoldisulfonic acid and hydrazine sulfate methods of nitrate analysis. The HPLC method requires a smaller sample size than either previous method, which allows ongoing nitrate analysis of an aqueous soil sample with little perturbation of the system.

HPLC analysis of various soil extractants

The soil extractions obtained from silver sulfate-copper sulfate, sodium bicarbonate, water and 1:1 methanol-water extractions were analyzed by HPLC. Except for soil P2, water extractions were the most accurate; silver sulfate-copper sulfate extractions were the least (Figure 6). A decrease in the clay content of the soil appears to decrease the accuracy of the sodium bicarbonate extraction; nitrate recovered for T1 > P2 > P1. The 1:1 methanol-water extraction gave unpredictable results between the soils but reproducible values for each soil type. The reason for the non-linear (T1) (Figure 6c) and linear (P1) (Figure 6a) increases in nitrate recovery using 1:1 methanol-water as an extractant are unknown. Analysis of soils with varying physical and chemical properties may reveal the source of this anomaly.

The results indicate that 1:1 methanol-water is an effective eluant for the analysis of nitrate and nitrite by RP-HPLC. Water extractions of soil containing less than 100 ppm nitrate nitrogen can be confidently analyzed. The use of 1:1 methanol-water as the mobile phase and water as the soil extractant results in a substaintial savings in the cost of nitrate analysis.

ACKNOWLEGEMENTS

The authors wish to thank the Dr. P. C. Loewen, Department of Microbiology for the use of his HPLC equipment. The authors wish to thank NSERC and the Canadian Wheat Board for their financial assistance in the form of fellowships for TCK.

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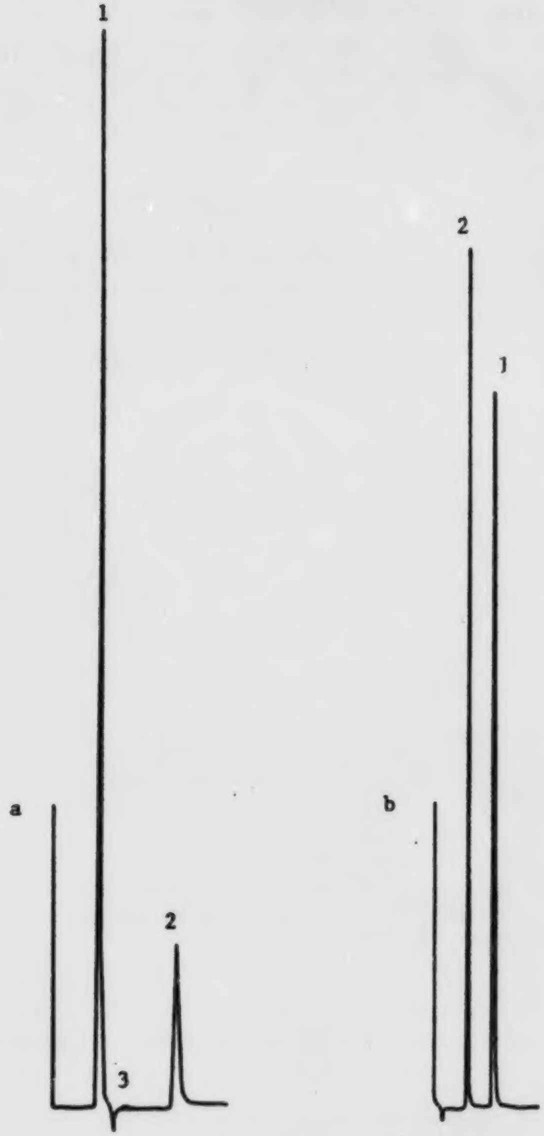


Figure 1: Comparison of chromatograms produced by 50 mg/L nitrate, 50 mg/L nitrite, and 400 mg/L phosphate with a) 1:1 methanol/water pH 3.0 and b) Low UV PIC A. Peaks: 1 = nitrate, 2 = nitrite, and 3 = phosphate. Conditions: Lichrosorb RP-18 column, flow rates - 1 mL/min for 1:1 methanol-water and 2.4 mL/min for Low UV PIC A, 0.1 in/min chart speed.

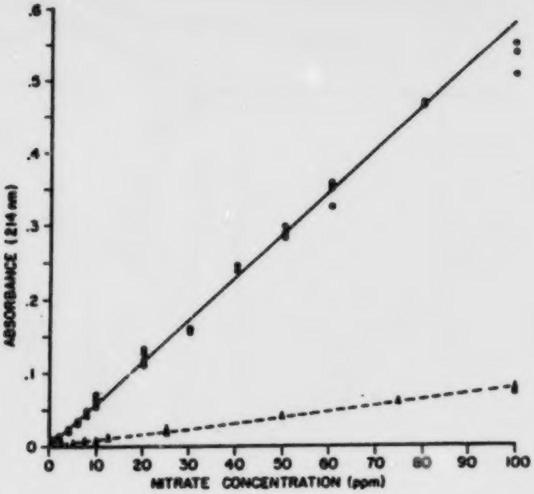


Figure 2: Standard curves for nitrate generated with 1:1 methanol/water (O———O) and Low UV PIC A (X- - -X). A minimum of 3 assays for the 1:1 methanol/water and 2 for the Low UV PIC A were performed at each indicated concentration. HPLC analysis of nitrate at 100 mg/L with 1:1 methanol/water was not included in the statistical analysis.

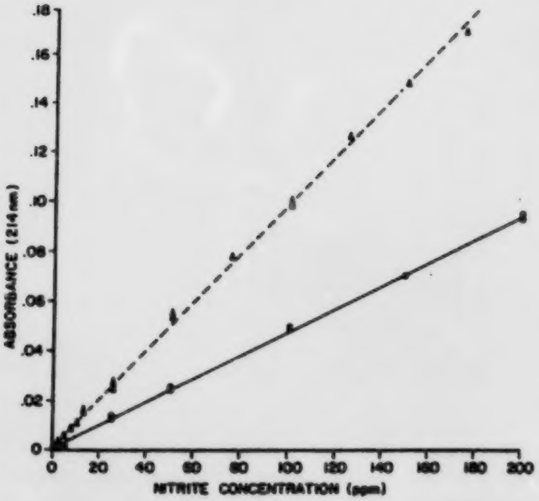


Figure 3: Standard curves for nitrite generated with 1:1 methanol/water (O———O) and Low UV PIC A (X- - -X). Each concentration assayed represents a minimum of 2 analysis.

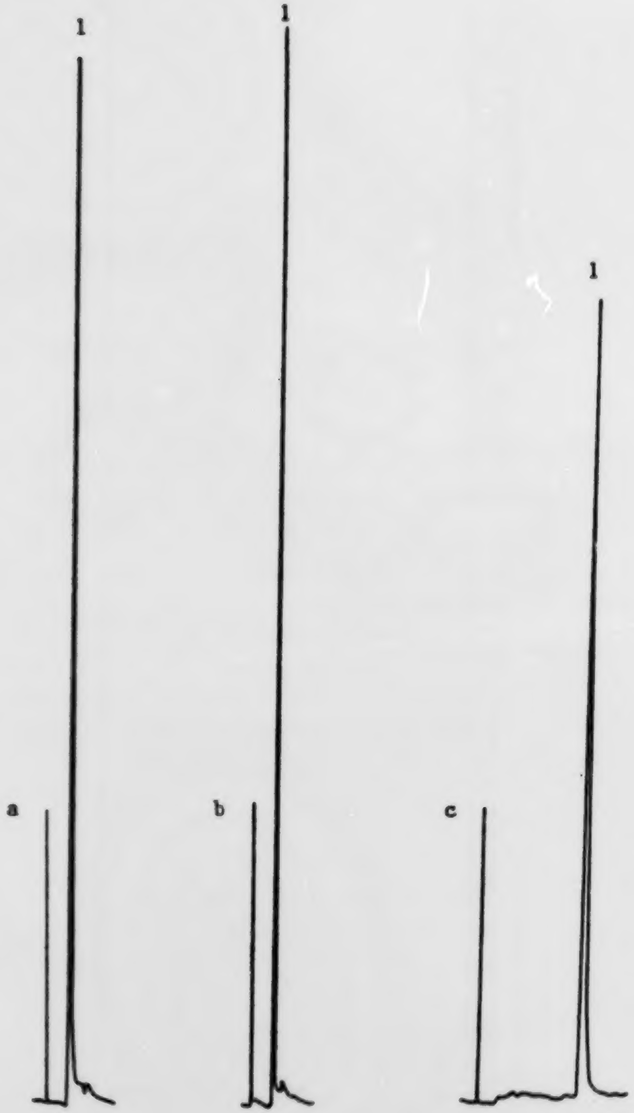


Figure 4: Chromatograms of soil extracts. A and c are soils extracted with water, b) is soil extracted with 1:1 methanol/water. A and b analyzed with 1:1 methanol/water as the mobile phase with conditions as for Figure 1. C was analyzed with Low UV PIC A as the mobile phase. Conditions as for Figure 1 except the flow rate was 2.5 mL/min.

Figure 5: Nitrate analysis of soil a) P1, b) P2, and c) T1 by the phenoldisulfonic acid (▲– – –▲), hydrazine sulfate (●—— —●), and HPLC methods (■- - - -■). Water was used as a soil extractant for HPLC analysis. HPLC conditions as for Figure 1.

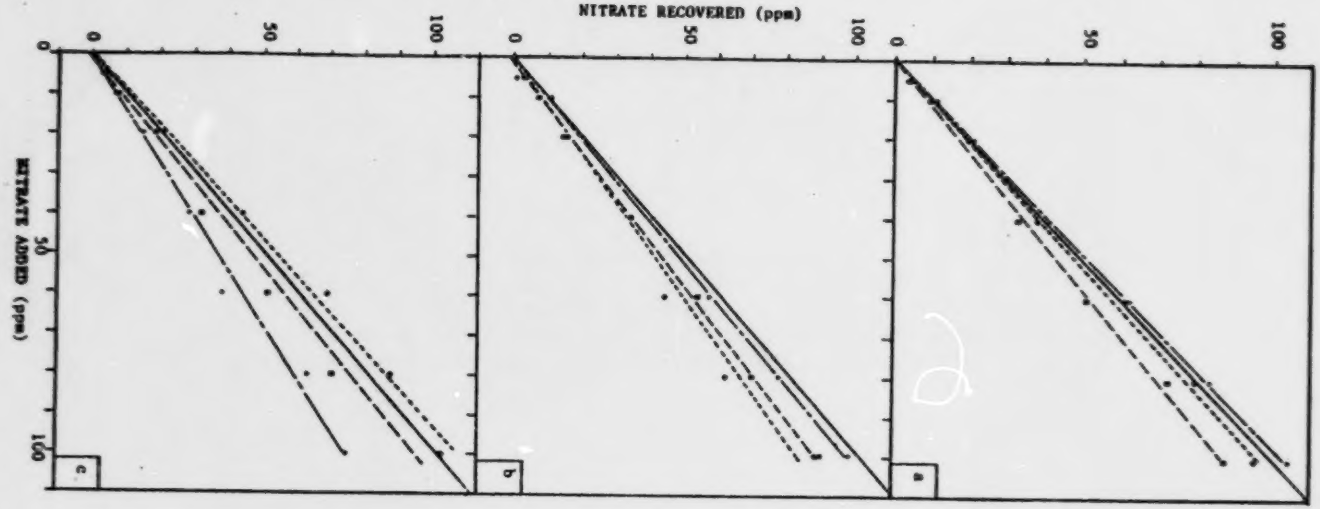
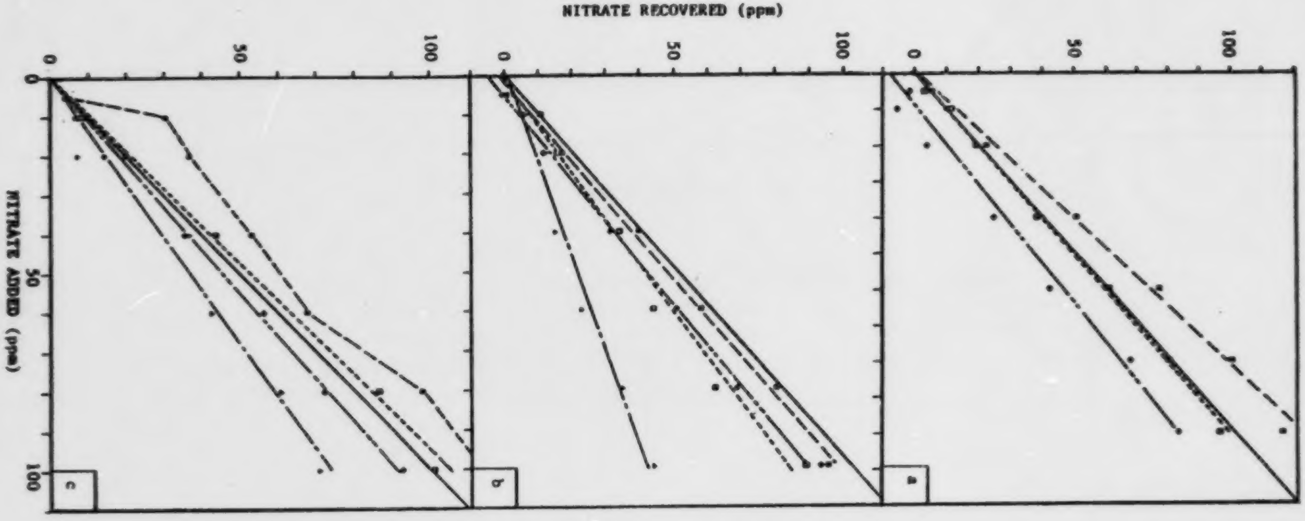


Figure 6: Comparison of silver sulfate-copper sulfate (▲------▲), water (□-----□), 1:1 methanol-water (■----■), and sodium bicarbonate (●--·-●) as nitrate extractants for HPLC analysis of nitrate in soils a) P1, b) P2, and c) T1. HPLC conditions as for Figure 1.



Ionic Transport in Soil with Ion-Exchange Reaction

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Abstract:

Mathematical analysis of ionic transport phenomena in a soil-like material initially saturated with a cation was investigated. Movement of displacing and displaced ions into the soil depth was studied as related to the ion exchange selectivity coefficient ("ion exchange equilibrium constant"), feed concentration, cation exchange capacity and valence of the ions under advective ("convective") condition.

The analyses showed that the movement of feed cation was retarded by the cation exchange reaction. The extent of the retardation and the shape of the distribution profile were governed by the selectivity coefficient. The displaced ion travelled with the speed of water. However, because of the continued desorption near the advancing front of the feed cation, there was a build-up of the maximum concentration of displaced ion in front of the displacing cation. This "snow-plow" effect, the term used to describe the build-up of the displaced ion, was found to be related to the incoming concentration, cation exchange capacity and selectivity coefficient.

The amount of cation removed by a unit amount of input quantity was related to the selectivity coefficient. A large selectivity coefficient favored the efficient removal of native cation by the displacing ion.

A monovalent ion replacing a divalent ion adsorbed on the clay, or a divalent replacing monovalent on the clay, was related not only to the selectivity coefficient, but also to the concentration of an ion and the cation exchange capacity. High concentration of a monovalent ion favored the displacement of divalent cation. However, if the concentration was low, divalent ion replaced monovalent ion very effectively. High cation exchange capacity favored the divalent ion over monovalent ion, thus making the displacement very effective.

The analyses showed a number of very interesting observations that might occur near the fertilizer bands.

Introduction

When an ammonium fertilizer, in a form of pellet, was applied to a soil, for example, a number of reactions take place near the fertilizer band. The concentration of ammonium is very high near the pellet site and this causes the diffusive movement of ammonium away from the site. The movement of a cation, like ammonium, in a soil which has cation exchange capacity, is quite different from an ordinary diffusion process occurring in an aqueous medium. Since the ammonium ion is a cation, it is adsorbed by the exchange material. Consequently the mobility of the ion is retarded. The adsorption process causes the native cation to be freed from the exchanger materials. The freed cation is now subject to the diffusion process. Since the ion-exchange reaction is a competition reaction, the adsorption and desorption of ions are controlled by the relative concentration of displacing ion, such as ammonium, and the ion being displaced, such as calcium. The cation exchange capacity and ion exchange selectivity coefficient also affect the distribution of ions, and they, in turn, affect the magnitude of ionic transport in soil.

With these in mind, general transport equations for two ions, which interact with each other in the form of ion exchange reaction, were formulated. The equations, which can not solved by an analytical method, were approximated by a numerical method. Various conditions of interest were chosen for the analyses.

Analysis

In order to understand the phenomena that occur near the fertilizer band, a simulated condition, in which a known concentration of a cation solution is being fed on to a soil column initially saturated with a different cation, was chosen for the analysis. The soil was assumed to contain no free ion in solution initially so that any change in solution concentration was assumed to be due to either influx or to the desorption phenomena. The transport equations subject to above initial conditions were solved numerically under several different conditions to observe the effects of selectivity coefficient, concentration, cation exchange capacity and valence of ions upon transport characteristics of ion in soil.

The results obtained with 100 mM of input concentration supplied onto a soil with cation exchange capacity of 100 mM (which corresponds to CEC of 5 meq/100g, bulk density of 1 with 50% volumetric moisture content),selectivity coefficient, $K = 1$, feed speed, $v = 0.02$ cm min^{-1} are shown in Fig. 1. Since the feed speed was 0.02 cm min^{-1}, the front of feed solution should have reached 5 cm at $t = 250$ min. The center of the moving front, which corresponds to the position where the concentration was one half of the input value, moved up to near 2.5 cm indicating that the mobility of A^+ was nearly one half of that of water as was expected (since the magnitude of CEC and input concentration were equal). As time progressed, the depth of penetration of A increased. The native cation, B, which was not present in the soil solution, was desorbed from the exchanger. The concentration profile was similar to a slightly skewed normal distribution curve, with the maximum just in front of the displacing solution. The magnitude of the maximum increased with time, and reached to the same value as that of incoming solution.

If the value of K was changed to 10, expressing that the incoming cation had 10 times the affinity to the exchanger as compared to the native cation, the patterns of distribution of ions changed (Fig.2). Even though the average speed of displacing ion, A, was not affected by the magnitude of K, the front of displacement became much sharper than those observed in Fig. 1. The distribution pattern of the displaced ion, B, also changed. The magnitude of the maximum of B was greater than that observed in Fig. 1 under same elapsed time. At t = 500, the concentration of B became virtually identical to that of the incoming concentration. The distribution pattern of B was very skewed. It was very sharp on the left side while it was quite diffused on the right. The ions on the diffused side which were observable at the deeper depth originated from the surface of the soil and was transported downward by water. The speed of the displaced ion was the same as that of water. Consequently the distribution patterns were very diffuse. It is worth mentioning that a chemical reaction, such as formation of $CaCO_3$ and precipitation as solid, may take place if displaced ion was Ca.

Lowering the magnitude of K to 0.1, showed quite a drastic change in the distribution pattern (Fig.3). Depth of penetration of A was extended deep into the soil with a very gradual slope. The average speed of A was faster than those observed previously. On the other hand, the concentration of displaced ion, B, was much lower and extended throughout the column. Penetration of A deeper into the soil indicated that the replacement of B by A was not very effective. Consequently the ion B was also present near the soil surface even after 500 min.

Sum of A and B corresponds to the anion concentration. Since anion transport should not be affected by the magnitude of K, the anion transport should be the same among those shown in Fig. 1, 2 and 3 irrespective of K under the same elapsed time. It was indeed found to be the case. Consequently, it is seen that under the same amount of salt transport with identical input concentration and cation exchange capacity, the magnitude of incoming ionic transport was controlled by the magnitude of K. Also the pattern of distribution of desorbed ion was governed by K. The concentration at the maximum of desorbed ion was the greatest with largest value of K at the early stages of transport before it reached the concentration of incoming solution.

The incoming ion A which was not present in the soil at the onset of calculation replaced B and became itself an exchangeable ion. The amount of A adsorbed was equivalent to the amount of B desorbed. The distribution profiles of adsorbed ion at t = 500 min when K = 10, 1 and 0.1 are shown in Fig. 4. When K = 10 and 1, the patterns of distribution of A in the adsorbed phase (Fig.4) and A in solution (Fig.1 and 2) are very similar. However, the when chosen value of K was 0.1, the amount of adsorbed A at a particular position was less than that in solution. The amount of A adsorbed or B replaced was very small as compared to A in solution. This indicated that the effectiveness of replacement of a cation from a column by elution technique was dependent upon the magnitude of K. The amount of A adsorbed on the exchanger materials were found to be 52.3%, 49.9% and 32.0% for $K = 10$, 1, and 0.1 respectively. The results indicated that the removal of an ion from an exchanger material is more effective if one uses the ion with large K value.

A monovalent ion replacing a divalent ion adsorbed on the exchanger, or the replacement of monovalent ion by divalent ion show almost identical patterns of distribution when $A_o = 100$, $K = 1$ and $R = 100$ (Fig.5). If the concentration of the divalent ion in solution was expressed in term of normality rather than molarity, then the results shown in Fig. 5 and those shown in Fig. 2 became almost identical.

If, however, the value of R was increased to 500, while keeping the magnitudes of A_o and K the same as before, then the pattern of distribution changed (Fig.6). Since the magnitude of R was 500 and A_o was 100, the magnitude of travel of A was rather small. There was a difference , however, between the distribution patterns of A^{++} replacing B^+ and A^+ replacing B^{++}. When A^{++} replaced B^+, the slope of moving front of A^{++} was very sharp, while the front of A^+ was rather gradual. Consequently, it could be concluded that the effectiveness of A^{++} in replacing B^+ was greater than A^+ replacing B^{++}. The distribution pattern of displaced B supports the above conclusion. The displaced B^+ concentration reached to 100, while B^{++} concentration (expressed in N) did not reach 100. Consequently the total amount of B^+ replaced by A^{++} was greater than B^{++} replaced by A^+. Under the condition when R was increased to 500 from 100, the effectiveness of divalent ion in replacing monovalent ion adsorbed in the soil material increased.

If the magnitude of R was reduced to 20, while other parameters were kept the same as before, the magnitude of penetration of A^+ and A^{++} increased as was expected (Fig.7). Average distance of water movement was 7.5 cm, and the average distance of travel of A^+ and A^{++} were nearly 6.25 cm. Thus, the retardation factor could be used to obtain the average distance of travel of A. Under the chosen conditions, the distribution patterns of A^+ and A^{++} were reversed from that observed previously. The magnitude of penetration of A^{++} was greater than that of A^+. Also the magnitude of the maximum concentration of displaced B^{++} was greater than that of B^+, indicating that monovalent ion was more effective in replacing B^{++} than A^{++} replacing B^+.

The magnitude of maximum concentration of B^{++} was nearly 40, which was twice as much as the CEC value (if all B^{++} was desorbed into adjacent soil water, it should have been 20) and the maximum was located at the wetting front, which was 7.5 cm. Thus , if an incoming ion concentration was very high, the displaced ion concentration exceed the local CEC.

The results, even though they are all based on theoretical analyses, are interesting and have many practical implications. The results show how an ion travels into ion-exchange materials such as soil. The magnitude and distribution patterns are altered by the choice of ion which displaces the native ion in soil.

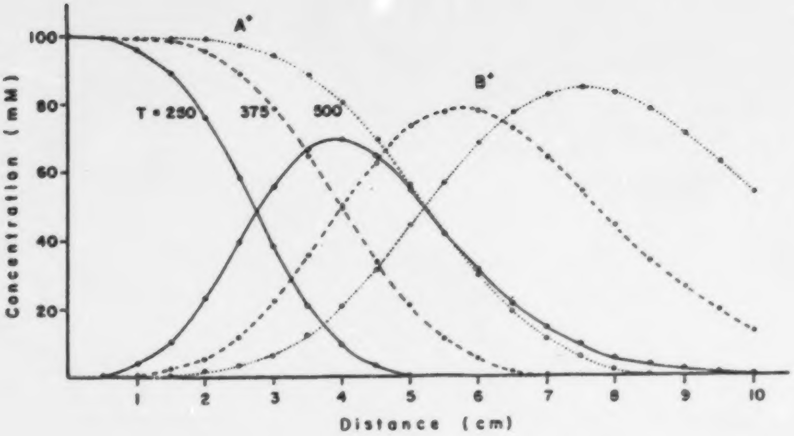

Fig. 1. Displacement of B^+ by A^+ at 3 different times.
K = 1, v = 0.02, R = 100, D = 0.005.

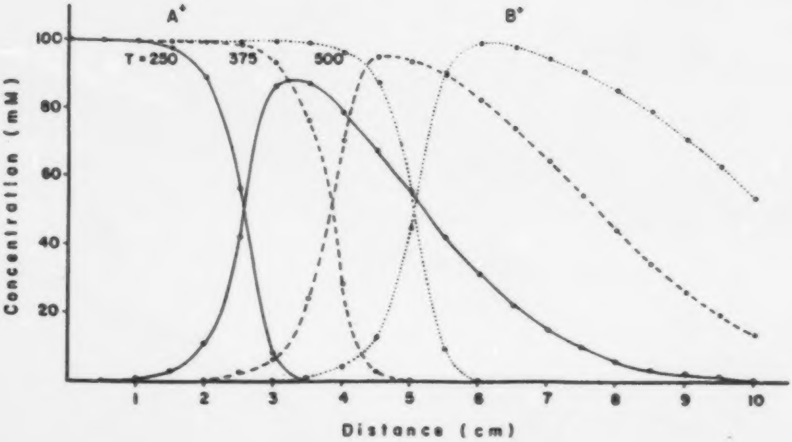

Fig. 2. Displacement of B^+ by A^+ at 3 different times.
K = 10, v = 0.02, R = 100, D = 0.005.

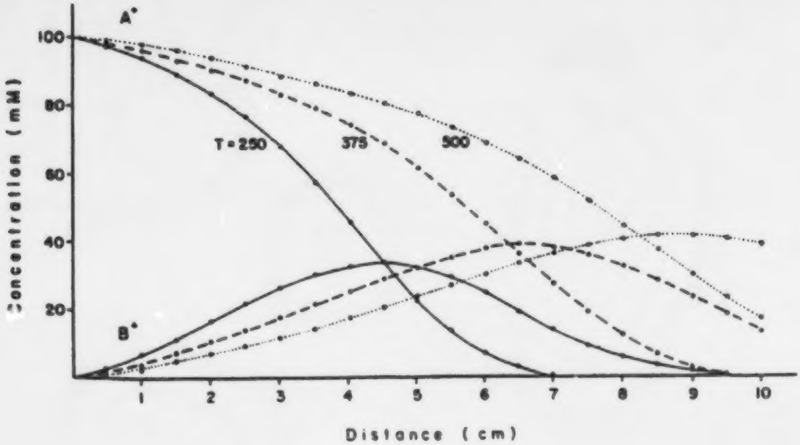

Fig. 3. Displacement of B^+ by A^+ at 3 different times.
$K = 0.1$, $v = 0.02$, $R = 100$, $D = 0.005$.

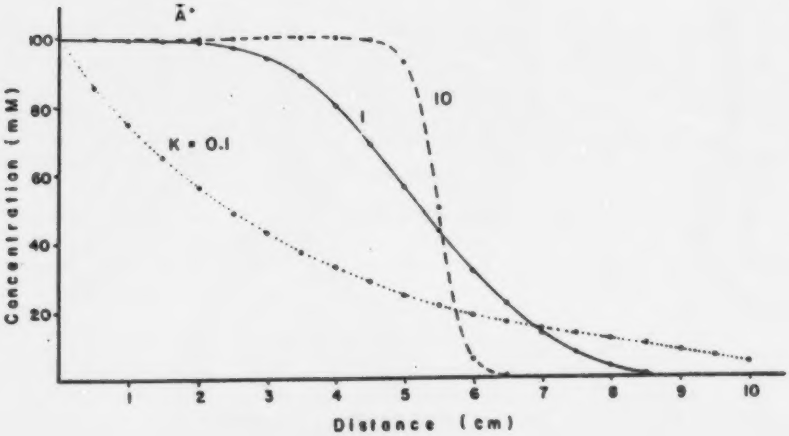

Fig. 4. Adsorbed A^+ and B^+ in the exchanger with 3 different K.
$t = 500$, $R = 100$.

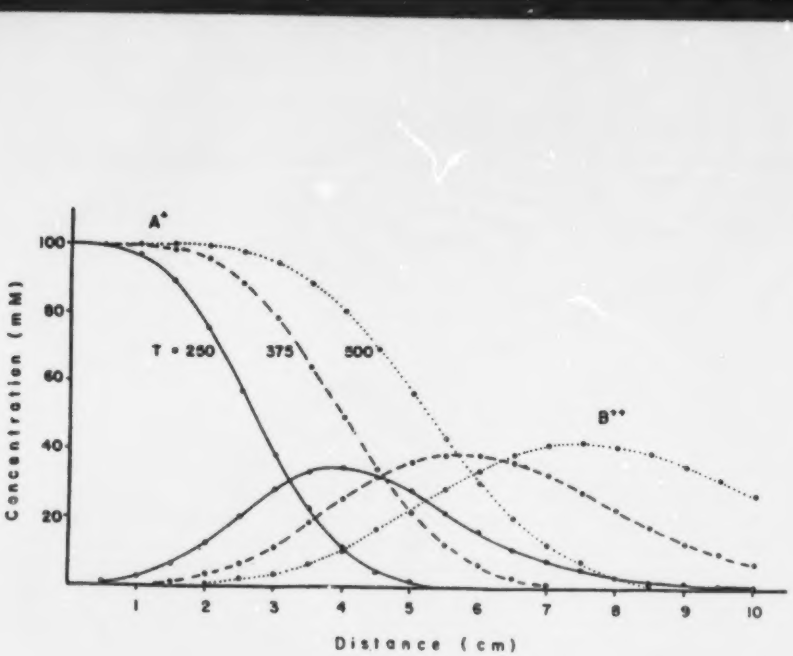

Fig. 5. Displacement of B^{++} by A^{+} at 3 different times.
$K = 0.1$, $v = 0.02$, $R = 100$, $D = 0.05$.

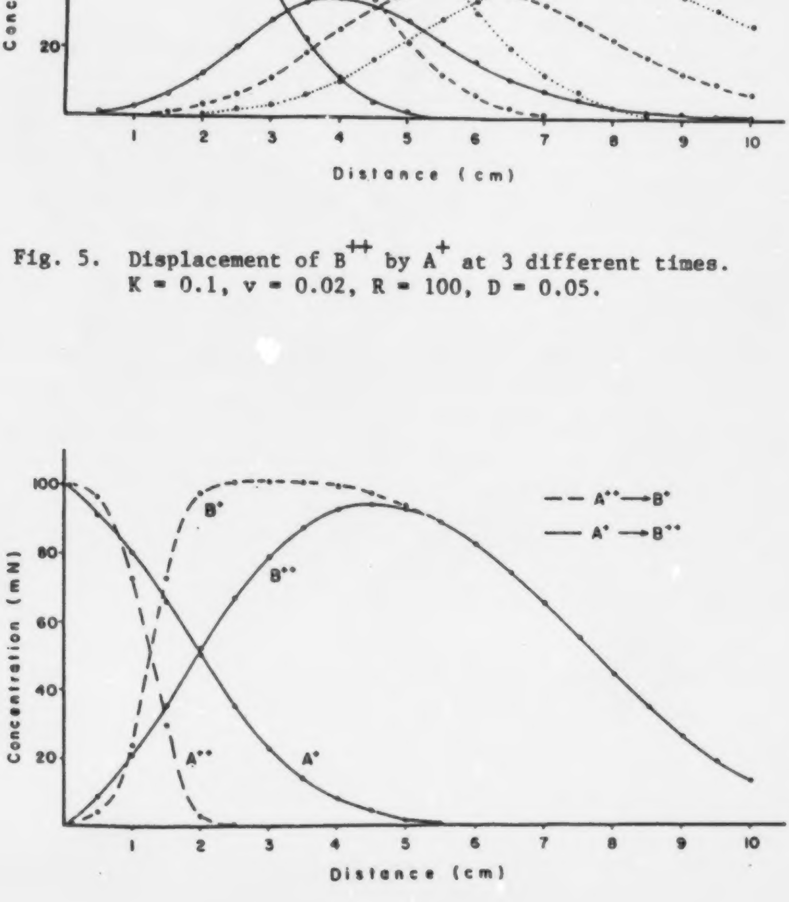

Fig. 6. Monovalent and divalent displacement.
$t = 375$, $R = 500$.

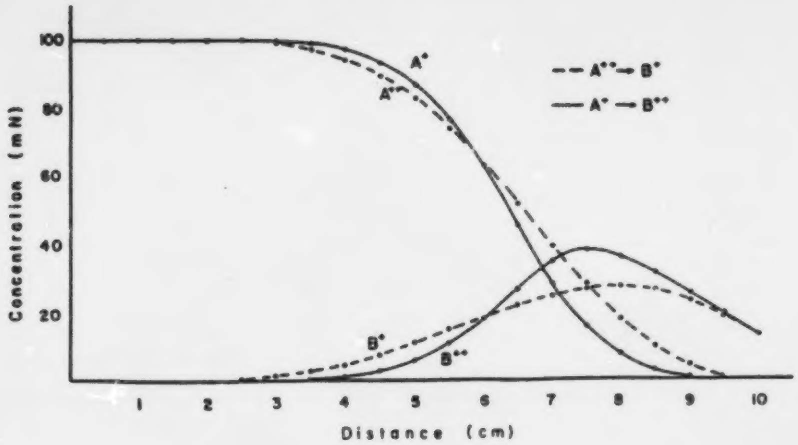

Fig. 7. Monovalent and divalent displacement.
$t = 375$, $R = 20$.

"MAKING THE MOST OF NITROGEN"

RECOMMENDED PRACTICES RESULTING FROM RECENT RESEARCH IN ALBERTA

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INTRODUCTION

Researchers in Alberta undertook a five year research project in 1979 called, "Making the Most of Nitrogen". Much of the funding for the project was provided by the Alberta Heritage Trust Fund - Farming for the Future Program. The purpose of the project was to determine why large differences in nitrogen utilization by crops was occurring due to source, method, and time of application; and to develop methods of increasing N efficiency.

Research prior to 1979 had established that large differences in the effectiveness of N fertilizer often occurred between fall and spring and between broadcast and band treatments. Also, large differences in effectiveness were obtained between ammonium and nitrate sources of nitrogen. However the results did not provide an adequate basis to establish guidelines for more effective methods of nitrogen application under the various soil-climatic conditions throughout the province. As a result of the research conducted under the "Making the Most of Nitrogen" project, we have been able to develop guidelines as to the relative effectiveness of sources, methods, and times of application for various soil-climatic conditions. The purpose of this paper is to briefly review this work and present the recommendations that have been developed. Papers summarizing the "Making the Most of Nitrogen" project were presented at the Alberta Soil Science Workshop 1984 and are listed in Table 1.

Table 1 List of papers from the "Making the Most of Nitrogen" study presented at the Alberta Soil Science Workshop - 1984

TABLE OF CONTENTS

Regional and environmental influences on nitrogen use efficiency
J.B. Bole, D.C. Penney, J.T. Harapiak, and S.S. Malhi...............1

Microbiology of soil and fertilizer nitrogen use efficiency
W.A. Rice, J. Ashworth, A.T. Blades, and W.B. McGill...............19

Soil nitrogen tests as affected by time of sampling
L. Kryzanowski, A.M.F. Hennig, and S.S. Malhi......................30

Changes in crop available nitrogen in soils in Winter:
Mineralization, immobilization, and denitirification
D.J. Heaney, A.T. Blades, S.S. Malhi, and M. Nyborg................46

Tillage, straw, and nitrogen
M. Nyborg and S.S. Malhi...60

Efficiency of fall-applied nitrogen as influenced by method
of placement and date of fall application
S.S. Malhi, M. Nyborg, J.T. Harapiak, and D.C. Penney..............75

Efficient use of nitrogen - the nitrogen and phosphorous
interaction
J.T. Harapiak and D.C. Penney.....................................102

The use of nitrification inhibitors in attempts to improve the
efficiency of plant uptake of fertilizer-N and soil mineral-N
J. Ashworth, S.S. Malhi, D.C. Penney, N.A. Flore, A.T. Blades,
and A.M.F. Hennig...115

DENITRIFICATION AND IMMOBILIZATION

Research conducted in the early and mid 1970's by Dr. Marvin Nyborg, University of Alberta and several of his graduate students produced numerous results that drew into question the stability of fertilizer and soil mineral-N during the late fall, winter, and early spring period. Large apparent losses of fall applied N lead to reserach with nitrification inhibitors and monitoring of mineral N in the soil during the late fall, winter, and early spring period. Results from overwinter monitoring of mineral N repeatedly showed a pattern similar to that illustrated in Figure 1.

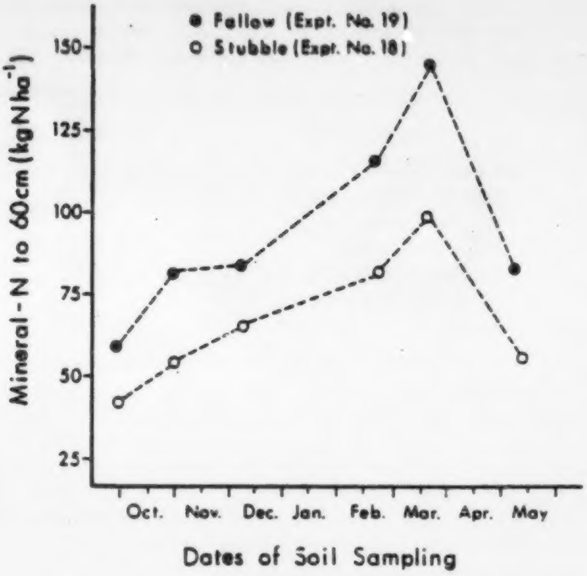


Figure 1. Changes in soil mineral N content from fall to spring on fallow and stubble sites at Ellerslie.

These results and results of studies correlating soil test nitrogen in fall and spring with crop yields as shown in Tables 2 and 3 challenged the concept that soil mineral N and fall applied fertilizer N were stable during the late fall to early spring period.

Table 2 Correlation NO_3-N and Mineral N (NH_4 + NO_3-N) of fall and spring soil samples with yield of barley grain in 82 field tests conducted over eight years from 1973-74 to 1980-81 (Malhi, 1984).[+]

Soil Test Nitrogen (0-30 cm)	Check Yield (r)
NO^3-N (Fall)	0.55
NO_3-N (Spring)	0.72
Mineral N (Fall)	0.54
Mineral N (Spring)	0.71

[+] Kryzanowski et al. - 1984

Table 3 Correlation of NO_3-N and mineral N (NH_4-N + NO_3-N) of early fall, late fall, and spring soil samples with yield of barley grain in 26 field tests conducted over two years 1978-79 and 1979-80 (Malhi, 1984).[+]

Soil Test Nitrogen (0-30 cm,)	Check Yield (r)
NO^3-N (Early Fall)	0.34
NO_3-N (Late Fall)	0.63
NO_3-N (Spring)	0.66
Mineral N (Early Fall)	0.33
Mineral N (Late Fall)	0.69
Mineral N (Spring)	0.65

[+] Kryzanowski et al. - 1984

Disappearance of NO_3-N in early spring, poor results from fall applied NO_3-N, and encouraging results with the use of nitrification inhibitors all indicated that denitrification losses occurred in the early spring, during or just after snow melt.

Results showing large differences in the effectiveness of broadcast urea due to the date of application in fall indicated that nitrification of an ammonium N source in fall could lead to poor N use efficiency by crops (Table 4).

Table 4 The relative effectiveness of urea broadcast and incorporated in early, mid, and late fall in central Alberta.[+]

Date	Relative Effectiveness (%)[*]
Sep 20 to Oct 5	32
Oct 5 to Oct 20	50
Oct 21 to Nov 5	65

[+] Malhi et al. - 1984

[*] Compared to spring broadcast application

Evidence of immobilization and losses due to denitrification are shown in the results obtained in a study using N-15 (Table 5). These results, showing minimal losses due to leaching, are typical of the work conducted in central Alberta.

Table 5 Overwinter partitioning between loss mechanisms (1980-81)+

Soil	Immobilization	Leaching	Apparent Denitrification	Total Loss
	Percent of Added N-15			
Ellerslie Fallow	29.1	0.6	34.5	64.2
Ellerslie Stubble	52.1	0.1	46.0	98.2
Breton Fallow	20.8	0.6	49.7	71.1
Breton Stubble	6.8	Trace	78.4	85.2

+ Heaney et al. - 1984

POSITIONAL AVAILABILITY

Prior to and in conjunction with the "Making the Most of N" project, many field trials were carried out that compared fall broadcast, fall banded, spring broadcast, and spring banded nitrogen. The relative effectiveness of these treatments was highly variable. In contrast to the results outlined in the previous section which were obtained mainly in central Alberta, many of the trials conducted in other areas of the province showed relatively good results from fall application, particularly fall banded N. There was a strong influence of early growing season rainfall on the relative effectiveness of banded and broadcast nitrogen as shown in Table 6. Banding was much more effective than broadcast when early growing season rainfall was characterized as unfavourable.

Table 6 Relative effectiveness of spring banded and spring broadcast nitrogen fertilizer under various early growing season moisture conditions.+

Early Growing Season Rainfall	No. of Sites	Relative Effectiveness*
Unfavourable	12	166%
Fair-Good	10	126%
Excellent	12	102%

+ Harapiak (1981 - 1983)

* Yield increase from band ÷ yield increase from broadcast x 100.

RECOMMENDATIONS RESULTING FROM THE "MAKING THE MOST OF N" RESEARCH

As a means of assessing the influence of various soil and climatic conditions on the effectiveness of nitrogen fertilizer application, the results of all of the field trials were categorized as shown in Tables 7 and 8. Factors such as soil zone, fall moisture (very wet), drainage, spring flooding, and date of fall application all had a strong influence on the relative effectiveness of time and method of application. Also, in the comparison of fall banded and spring broadcast applications in Table 8, unfavourable early growing season precipitation resulted in fall banded urea being much more effective than spring broadcast. The superiority of banded nitrogen under these conditions is thought to be due primarily to the difference in the depth of N placement. When early growing season rainfall is low broadcast application results in shallow placement of N causing the fertilizer to be stranded in the surface few centimeters of dry soil.

Table 7 Effect of soil and climatic conditions on the relative percent yield and N uptake efficiency of fall and spring broadcast urea N fertilizers[+]

Soil Property	Relative Yield Increase*			Relative N Uptake**		
	No. of sites	Mean	S.D.	No. of sites	Mean	S.D.
Soil Zone						
Luvisolic***	17	63	28	16	63	28
Black	54	73	31	48	66	28
Dark Brown	15	86	22	11	80	24
Brown	13	97	32	13	89	19
Texture						
Coarse	18	84	31	18	80	23
Medium	48	75	28	42	68	27
Fine	33	74	35	28	68	30
Fall Moisture						
Dry	10	85	22	8	78	23
Moist	28	78	24	24	73	29
Wet	47	78	34	44	72	27
Very wet	8	61	40	8	52	31
Drainage						
Well drained	56	79	30	49	74	26
Moderately well	30	81	31	27	76	29
Imperfectly	13	56	28	12	45	20
Spring Flooded						
Yes	13	44	13	13	41	15
No	64	79	28	56	73	24
Date of Fall Application						
Before Oct 15	34	61	25	32	56	20
After Oct 15	64	84	31	56	79	28
Early Growing Season Precipitation						
Unfavourable	8	86	15	7	78	9
Fair	9	75	16	8	60	15
Favourable	9	90	29	5	75	22
Excellent	17	91	23	15	80	21
TOTAL	99	76	31	88	70	27

+ Bole et al. - 1984

* Relative yield increase $= \frac{\text{Yield increase from fall applied N}}{\text{Yield increase from spring applied N}} \times 100$

** Relative N uptake $= \frac{\text{Increase in N uptake from fall applied N}}{\text{Increase in N uptake from spring applied N}} \times 100$

*** Includes the Dark Grey soil zone.

Table 8 Effect of soil and climatic conditions on the relative percent yields and N uptake efficiency of fall banded urea as compared to spring broadcast and incorporated urea.+

Soil Property	Relative Yield Increase*			Relative N Uptake**		
	No. of sites	Mean	S.D.	No. of sites	Mean	S.D.
Soil Zone						
Luvisolic***	14	87	48	13	80	50
Black	42	107	48	37	97	40
Dark Brown	11	122	27	7	122	17
Brown	5	104	23	5	91	16
Texture						
Coarse	10	105	71	10	107	52
Medium	39	102	38	31	88	36
Fine	23	111	43	21	102	40
Fall Moisture						
Dry	10	116	33	8	119	28
Moist	18	119	34	14	105	32
Wet	37	101	52	33	92	45
Very Wet	5	81	19	5	76	37
Drainage						
Well drained	42	102	34	37	96	39
Moderately well	20	128	57	16	112	41
Imperfectly	10	72	32	9	66	31
Spring Flooded						
Yes	9	63	26	9	59	26
No	46	111	47	37	100	38
Date of Fall Application						
Before Oct 15	28	82	37	26	74	34
After Oct 15	41	121	43	36	112	38
Early Growing Season Precipitation						
Unfavourable	8	142	69	7	129	51
Fair	9	111	24	8	106	28
Favourable	9	120	25	5	110	18
Excellent	17	112	40	15	94	24
TOTAL	72	105	43	62	96	38

+ Bole et al. - 1984

$$\text{* Relative yield increase} = \frac{\text{Yield increase from fall applied N}}{\text{Yield increase from spring applied N}} \times 100$$

$$\text{** Relative N uptake} = \frac{\text{Increase in N uptake from fall applied N}}{\text{Increase in N uptake from spring applied N}} \times 100$$

*** Includes the Dark Grey soil zone.

In preparing guidelines for farmers, the results of the field trials were grouped into three soil-climatic categories. The relative effectiveness of spring broadcast, spring banded, fall broadcast, and fall banded nitrogen was determined for each category as shown in Table 9. Spring broadcast nitrogen was selected as a standard and assigned a rating of 100. The other methods of application within each category were rated as a percentage of spring broadcast.

Table 9 The relative effectiveness of methods and times of nitrogen application.

Method and Time of Application	Soil-Climate Categories 1 (dry)*	 2 (medium)	 3 (wet)**
Spring broadcast & incorporated	100	100	100
Spring banded	120	110	105
Fall broadcast & incorporated	90	75	65
Fall banded	120	110	85

* Although spring and fall banded nitrogen were equally effective in the research trials, fall banding may be more practical under farm conditions. The extra tillage associated with spring banding may dry the seedbed and reduce yields.

**In the research trials conducted in the higher rainfall areas, spring broadcast nitrogen was well incorporated and seeding and packing completed within a short period of time. Under farm conditions, shallow incorporation or loss of seedbed moisture resulting from deeper incorporation may cause spring broadcast to be somewhat less effective than shown here.

The soil-climatic categories used in Table 9 have the following general characteristics and locations for Alberta (see also Figure 2).

Category 1 - Well to moderately well drained soils in the Brown and Dark Brown soil zones and the Thin Black and Black zones south of the Bow River. These soils are seldom saturated during spring thaw but the surface few centimeters of soil is frequently dry during the growing season. Deeper placement of nitrogen is more effective as can be seen by the comparison of band and broadcast placement in both fall and spring (see Table 9).

Category 2 - Well to moderately well drained Black, Thin Black, Dark Gray, and Gray Wooded soils located in east central and northeastern Alberta, and the Peace River Region. Soils in this category may be saturated in early spring due to wet conditions in late fall or a deep snow pack but the condition is not as severe or frequent as in Category 3. These areas often experience relatively dry conditions during the early growing season and as a result deeper placement of nitrogen (10 cm to 13 cm) increases its effectiveness.

Category 3 - Gray Wooded and poorly to moderately well drained Black and Dark Gray soils in west central Alberta. This region often has a heavy snow pack and precipitation in May and June is usually higher than in other regions. This category also includes poorly drained soils or spring flooded conditions in all zones. Category 3 conditions occur most frequently in the area identified in Figure 2.

It is important to note that in all categories, fall broadcast nitrogen is the least effective method of application. Fall banded nitrogen, on the other hand, is more effective than spring broadcast and essentially equal to spring banded nitrogen except in Category 3 (wet conditions). Under wet conditions, fall banding is better than fall broadcast but less effective than spring application. In Categories 1 and 2, banding in either fall or spring is superior to broadcast applications.

The following summary comments are provided to help identify conditions where denitrification losses may occur and to outline methods of reducing these losses.

- Soil-climatic conditions that result in losses of fall applied nitrogen due to denitrification are:
  - i) wet conditions in fall prior to freeze-up,
  - ii) deep snow pack or heavy precipitation during spring thaw, and
  - iii) poorly drained soils - both internal and surface drainage

  (Note: Soils that are normally considered to be well drained can remain saturated and in effect are poorly drained until the subsoil thaws and allows moisture to move down.)

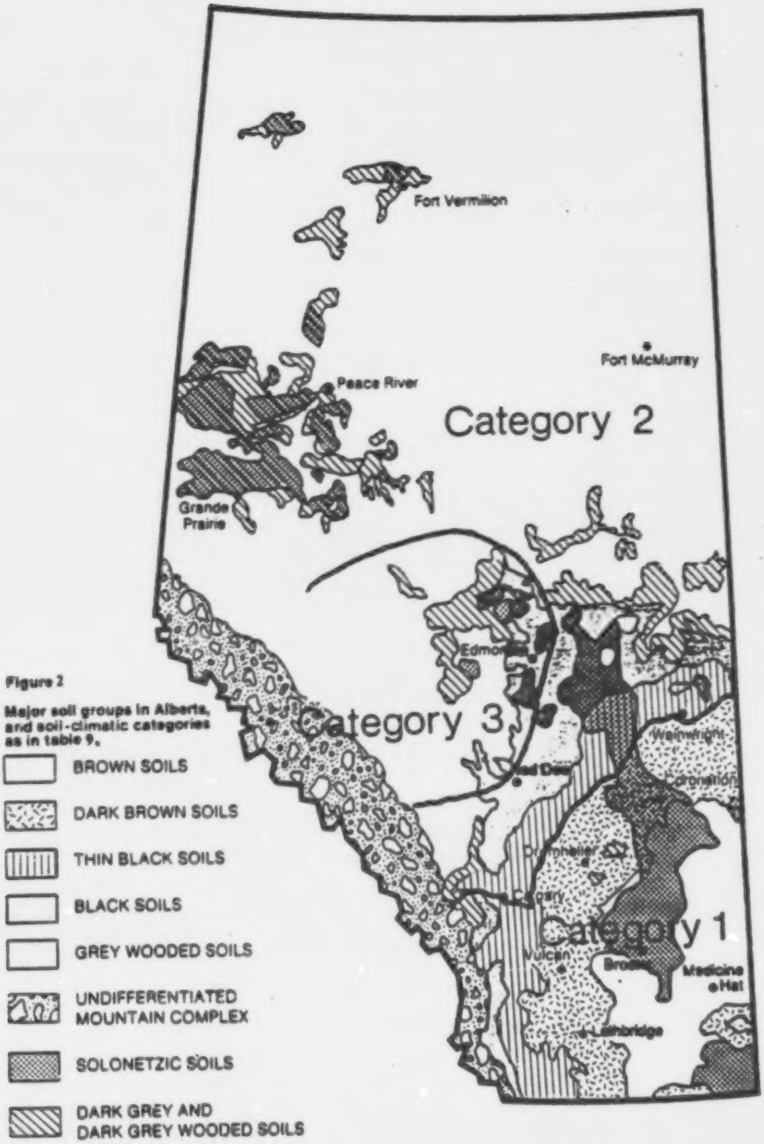
- Losses of fall applied nitrogen can be prevented or reduced by:
  - i) Applying an ammonium form of nitrogen such as urea or anhydrous ammonia,
  - ii) Applying the fertilizer in late fall (after mid-October or when soil temperatures are less than 7°C.), and
  - iii) Band placement using a relatively wide band spacing (30 cm to 45 cm) and narrow openers to concentrate the fertilizer as much as possible.

PHOSPHORUS PLACEMENT

The rapid acceptance of pre-plant banding of nitrogen fertilizers has created a demand for information on the effectiveness of phosphate applied in a common band with nitrogen as a convenient alternative to seed row placed phosphate. Trials in Alberta comparing seed-row placed phosphate and phosphate banded with nitrogen have generally shown similar results. In 39 trials with cereal crops in Alberta, the average yield increase from seed-row placed phosphate was only 14 kg/ha greater than deep-banded phosphate. Similar to the situation with

Figure 2

Major soil groups in Alberta, and soil-climatic categories as in table 9.


Fort Vermilion
Fort McMurray
Peace River
Category 2
Grande Prairie
Edmonton
Category 3
Red Deer
Wainwright
Coronation
Drumheller
Calgary
Category 1
Vulcan
Brooks
Medicine Hat
Lethbridge
BROWN SOILS
DARK BROWN SOILS
THIN BLACK SOILS
BLACK SOILS
GREY WOODED SOILS
UNDIFFERENTIATED MOUNTAIN COMPLEX
SOLONETZIC SOILS
DARK GREY AND DARK GREY WOODED SOILS

nitrogen, the effectiveness of the application methods was influenced by soil-climatic conditions. In the trials conducted under low rainfall conditions, phosphate banded with nitrogen was more effective than banded nitrogen and seed-row placed phosphate. In the trials conducted under higher rainfall conditions, seed-row placed phosphate was more effective.

In central and northern Alberta, early growing season rainfall and the available phosphorus content of the soil influenced the effectiveness of the method of application. As demonstrated in Table 10, the effectiveness of banded and seed-row placed phosphate changes between dry and wet years at the same location. Seed-row phosphate was more effective when early growing season rainfall was favourable (1981) and deep banded phosphate was more effective when the early growing season precipitation was below normal.

TABLE 10. Annual variation in barley response to seed row[+] vs. deep banded phosphate in north-central Alberta.

Year	Early Growing Season Rainfall (seeding to June 30th)	Yield Difference[*] (kg/ha)
1981	Favourable (Avg. 50.8 mm)	+139
1982	Below Normal (Avg. 6.4 mm)	-100

Based on average of three separate trials
+ Harapiak and Penney - 1984
* yield of (deep banded N + seed row P) minus (N-P deep banded)

As demonstrated in Table 11, soil phosphorous levels also had an important influence on the effectiveness of phosphate application methods. Phosphate applied in the seed row was more effective on low phosphorous soils and deep banded phosphate was more effective on medium phosphate soils.

TABLE 11. Response of barley to seed row vs. deep banded phosphate as influenced by soil test P levels at 12[+] locations in north-central Alberta (ADA 1981 & 1982).

Soil Test P Category	Yield Difference[*] (kg/ha)
Low (27 kg/ha)	+200
Medium (27-55 kg/ha)	-228

+ Harapiak and Penney - 1984
* Yield of (deep banded N + seed row P) minus (N-P deep banded).

Based on these results the general guidelines now being given for phosphate application based on soil-climatic conditions are:

1. In the Brown and Dark Brown soil zones, deep banded phosphate is generally equal to or slightly better than seed-row phosphate.

2. In central and northern Alberta and on irrigated soils seed-row phosphate is generally equal to or better than deep banded phosphate.

3. In central and northern Alberta and on irrigated soils, split application of phosphate (10 to 15 kg/ha in the seed-row and the remainder deep banded) have been equal to or better than placing all of the phosphate in the seed-row.

4. In a limited number of trials, split applications of phosphate have been the most effective method of application for canola.

REFERENCES

1. Papers as listed in Table 1, published in the 21st Annual Alberta Soil Science Workshop Proceedings, 1984. Copies of the proceedings are available from: Agriculture Secretary, Faculty of Extension, University of Alberta, Edmonton, Alberta T5G 2GH.

SOIL PHYSICAL PROPERTIES OF SELECTED SOILS ON TILLS AND LACUSTRINE DEPOSITS IN MANITOBA

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Canada-Manitoba Soil Survey

In the past several years, a considerable effort has been devoted to the measurement of physical properties of soils, in conjunction with an upgrading of the data base on established soil series. Personnel involved in productivity model-building, land and interpretive evaluations indicated a lack of data on the physical parameters; most of the parameters have been described in general terms and not accompanied by actual measurements. Some of the physical parameters include available water holding capacity, hydraulic conductivity, infiltration rate and bulk density.

Properties such as available water capacity are used in the ratings for agricultural capability, irrigation suitability, picnic areas, playgrounds; hydraulic conductivities are used in the rating for sanitary landfill, irrigation suitability, reservoir and lagoons, septic tank absorption field, playgrounds and campgrounds. Infiltration information would be desirable for irrigation application and for runoff or water erosion evaluation.

A review of available information on field capacity, available water and bulk density (Zwarich 1963) indicated that most data reported in the past was dominantly in the lacustrine deposits of S.C. Manitoba, with minimal information on the upland tills, high lime tills, high carbonate lacustrine, and more northerly areas. It was also noted that for a number of soils, the available water at the lower depths was considerably higher than similar strata at intermediate depths; these increased values at the lower depths were considered to be influenced by the water table or capillary fringe. While the reported available water values in the soils studied are possible under our climatic conditions, they may not represent the available water at field capacity. Field capacity and available water capacity of soils are defined in terms of moisture retention under freely drained conditions, normally for a period of 2 to 3 days following saturation. The acceptable definition is "the water content of a soil profile, usually the rooting zone, which has been thoroughly wetted by irrigation or rainfall and after the subsequent rate of drainage out of the profile has become negligibly small". The main problem in using this concept is deciding when the rate of drainage from the soil profile has become negligibly small.

The objective of this paper is to provide an update on the activities related to the physical properties, describe the methodology, and provide examples of specific site data in various landscapes (mainly the upland tills, high lime till and high carbonate lacustrine) and a summary of data within these and other landscapes.

PROCEDURES FOR PHYSICAL PROPERTIES DETERMINATION

Field capacity was determined on sites selected on the basis of soil type, suitability for flooding and accessibility, usually a field in fallow or intertilled area between cropland. The general procedure was similar to that reported by Cassel and Sweeney in North Dakota.

A water-tight dyke (1.5 x 1.5 m inside dimension) was constructed from 2 x 15 cm boards to enclose the plot. The square was placed on a relatively level surface, and the soil along the outside edge was removed to a depth of 5 to 8 cm. The frame was tamped into the trench and the soil on the outer edge was back-filled and tamped.

Within the frame, 2 access tubes (one PVC and one steel) for the neutron probe were installed to 130 cm depth. The soil was examined for relative moisture content; from this preliminary inspection an estimate of the water quantity to maintain saturation until the wetting front reached 120 cm depth was determined. An additional quantity of water for a sphere beyond the frame was included, then considered in terms of 1, 2, 3 or 4 barrels (45 gal.) of water.

Commercial tensiometers were installed at depths of 30, 45, 90 and 120 cm. In areas where a groundwater within 2 m was considered, a well was installed to a depth greater than 2 m at approximately 1 m from the outer edge of the frame. Since most sites were moist beyond the meter, 2 barrels of water were applied using gravity flow to a float valve which allowed a head of water 5 to 8 cm within the frame. (For soils with moist and dry zones, a preliminary moistening was done with 2 barrels in the latter part of the week, then 2 additional barrels were applied at the beginning of the following week). The time when surface drainage began (water-free) was recorded as time 0.

Soil samples were taken at several times (over a 10 day period) to determine the near-static moisture content (field capacity). Neutron probe readings were also taken at these sampling periods. Soil tensions (cb) were recorded prior to saturation and at various periods of sampling.

Field bulk density was determined by the post-hole auger method using approximately 15 cm depths. Incremental volumes were calculated using the depth increment (measurements of depth from the base to a reference point at the surface and recorded to the nearest unit or .5 cm) and the cross sectional sampling area (determined) of the auger. The total sample from this depth was weighed for field BD calculation. A representative portion of the soil was taken for gravimetric moisture content (dried at 105°C for 24 hours) and used to calculate the oven dried bulk density and volumetric water content. At a number of the sites, soil cores for moisture and bulk density were also taken during one of the sampling periods; cores were stainless steel cylinders 5 cm length and 4.7 cm I.D.

Permanent wilting percentage was determined by the standard 15 bar method (U.S. Salinity Lab Staff 1954) on profile samples taken at the site.

Infiltration rate was determined by the double ring permeability (U.S. Salinity Lab Staff 1954). The quantity of water (under a head) at various times was determined by direct measurement of the cm of water decrease in a reservoir of equal diameter to the inner ring. A constant head (Hw) was maintained at the surface by means of a float valve; the soil depth (L) was considered to be the depth of the inner ring in the soil. The infiltration rate was calculated for zero head of water by multiplying a factor of L/(L+Hw).

Saturated hydraulic conductivity was determined for surface horizons by the double ring (DR) method (above) and the air entry permeameter (AEP)method (Topp and Binns 1976); for subsurface layers the AEP was used.

RESULTS

A. Field Capacity and Drainage Time

Field capacity estimates are based on moisture content in the soil when the rate of drainage is relatively small. This relatively small rate generally stabilizes following the first day on some soils and after the second or third on others. Several examples of moisture content vs time after drainage began on the tills and lacustrine soils are provided (Figure 1). On the Darlingford soil (Figure 1a), a steady decrease of moisture occurred over a period of eight days; based on the sampling, the decrease in moisture following the first to the eighth day varied from approximately 2 percent (by weight) for the 90-105 cm depth to greater than 7 percent for the 30-45 cm depth. From this chart, it is difficult to establish what should be a sampling time. (On another Darlingford site, moisture change was similar to the following).

However, most other soils on relatively uniform material or on lacustrine deposits that became coarser with depth, the rate of change was near 1 percent following the second day to the eighth day or longer (Figure 1b,c,d). On the Plum Ridge soil, which had strata of loam and very fine sandy loam in the upper part of the profile grading to VFS and FS at lower depths, the moisture change following the first day to the ninth was less than 3 percent in the surface and negligible at the 90-105 cm depth.

On stratified or non-uniform soils where the textures become finer with depth, a steady state condition did not occur until the fifth day (Figure 2b). On the Plum Ridge, silty subsoil variant, the texture change at 82 cm was VFS to SiCL; within the 60 cm depth the moisture change in the VFS and finer layers above changed less than 1 percent between 67 hours to 118 hours, while in the VFS layer between 60 to 82 cm, the moisture content decrease was substantial from 29 to 20 percent by volume (19 to 13 percent by weight). Moisture change after the fifth day was minimal.

On the basis of the data presented, sampling for a steady state field capacity could be considered to be from 2 to 8 days for relatively uniform materials or materials that grade coarser with depth and under free drainage. However, on stratified materials that generally are finer textured with depth, it is recommended to allow at least 5 days for a relatively steady state to occur; on these soils sampling could occur between the fifth to ninth day (or slightly longer) following initial drainage.

B. Available Water Capacity (AWC)

Estimates of the AWC of soils are often arrived at by selecting an appropriate textural AWC and multiplying a depth interval(s), then summing over the desired root zone, often to 1.2 m. On relatively uniform materials, this procedure can be followed provided the individual is aware and knowledgeable of the texture, organic matter, mineralogy and has adequate examples for reference. However, on non-uniform or stratified materials as in the lacustrine basin, a large difference may occur depending on the strata sequence.

B.1 AWC on Very Strongly to Extremely Calcareous Lacustrine Soils

Before presenting the considerably less variable materials, an example on stratified lacustrine materials will be presented. Two Plum Ridge soils (very strongly to extremely calcareous) are characterized: a) typical with L to VFSL solum grading through VFS and FS at depth, and b) variant with a strata of SiCL below 82 cm.

In the typical, the moisture content was relatively stable following the first to ninth day (Figure 1d) and had an AWC to 1.2 m of 9.0 cm, while the variant did not reach a steady state until the fifth day and had an AWC to 1.2 m of 18.9 cm (21.8 at 67 h).

The only similarity in texture and AWC was in the upper 30 cm; below this depth, the AWC for texture were very different. In the typical soil, the VFSL strata had approximately half the AWC (.08 vs .15) than the LVFS strata of the variant; the VFS strata (.03) of the typical was one-fifth the VFS strata (.16) of the variant.

B.2 AWC on High Lime Tills

Available water capacity on the high lime stony till (greater than 40 percent $CaCO_3$ equiv.) are presented for the Aneda and Inwood soils (Figure 3); Aneda has an AWC to 1.2 m of approximately 17.2 cm and Inwood has more than 17 cm. The texture of the parent material is normally a loam, but may have pockets of coarser or finer texture within the profile depth. Bulk density (oven dry) are generally high (1.70 to 1.99 or more). It appears that high lime soils with a fairly uniform composition have a decreasing moisture content (field capacity) with depth, while those soils with greater variability (pockets of lighter and heavier texture) have a generally higher moisture content (field capacity) with depth.

Soils with thin sandy loam to loam overlays on high lime till (St. Malo series) had an AWC to 1.2 m of 18.2 cm. Soils with a mixture of clay and loam high lime (Libau, clay till variant) had an AWC to 1.2 m of 21.1 cm. A high lime soil with variable lenses or pockets of gravel (Inwood, gravelly variant or Beaverdam series) had an AWC to 1.2 m of 11.4 cm; bulk density in this modified till varied from 2.15 to 2.35 g/cc.

B.3 AWC on Upland Till

Field capacity and AWC on the upland tills (Darlingford, Erickson, in Figure 4) were relatively uniform within the horizons and amongst the various sampling areas. Two typical examples, the Darlingford and Erickson soils, representing the southern and central upland, respectively had AWC to 1.2 m between 21 to 22 cm; AWC for the subsoil are generally 0.18 cc/cc, some surface horizons may be slightly higher. Similar results for the Newdale soil were reported by Zwarich 1963; AWC to 1.2 m was 22.2 cm and AWC for the subsoil was calculated as 0.18 cc/cc.

C. Infiltration Rate

Infiltration rates are presented for a number of soils (under fallow) on the upland tills of the Newdale, Darlingford and Erickson series (Figure 5). The curves are presented for actual water entry under a head of approximately 3 cm, and reported on an adjusted zero head basis to correspond to an irrigation application rate or rainfall rate acceptance of the soil surface. The Newdale soils had a moderately rapid rate of 3.7 to 5.6 cm/30 min; the Darlingford soils had rates approximately half the values, 1.5 to 2.9 cm/30 min, of the Newdale soils. These values indicate that the surface horizons of the Newdale soils have a structure in the Ah (below Ap) that allows a relatively rapid water entry. The Erickson soil had a considerably lower infiltration rate, generally less than 1 cm/30 min. The lower rates were attributed to the influence of the Bt horizon, commonly occurring immediately below the Ap horizon and possibility of variable compaction due to cultivation practice.

On the higher lime till and lacustrine soils (Figure 6) a similar trend was observed. Soils with a good structure such as the Aneda had a rapid infiltration rate of 6.1 cm/30 min; no attenuation of the rate was observed over the two hour period as occurred for other soils. The Plum Ridge and Libau (clay till variant) had moderate rates of 3.9 and 3.1 cm/30 min, respectively. Imperfectly drained soils (Ladywood, Inwood soils) with a shallow A horizon and a Bt or Btj horizon had moderately slow rates; the Ladywood soil had a rate of 1.6 cm/30 min., while Inwood soil had 0.4 cm/30 min.

Saturated hydraulic conductivity can be calculated once the rate of water entry becomes constant (usually within two hours on soils that initially are moist or near field capacity). For the upland soils, the hydraulic conductivity in cm/hr was as follows: Newdale were 4.46 at Binscarth site and 5.43 at the Shoal Lake site; Darlingford were 3.51 at the Darlingford site and 2.48 at Thornhill site; Erickson ranged from 0.06 to 1.54 at the Russel site.

On the higher lime soils the hydraulic conductivity in cm/hr were as follows: Aneda 7.49, Plum Ridge 1.36, Libau 1.42, Ladywood 0.51, Inwood 1.13.

SUMMARY

A brief overview of the Soil Survey activities related to physical properties of soils was presented. Examples were provided to indicate that sampling time for field capacity could be taken after the second to eighth day following saturation and commencement of drainage on relatively uniform freely drained materials or on materials that grade coarser with depth below 1.2 m. On soils that are stratified or that grade finer at depth, the recommended sampling time is from the day 5 to 9 or more following saturation and commencement of drainage.

Available water capacity for various textures and to rooting depth of 1.2 m are provided for the upland tills; AWC to 1.2 m on the Darlingford and Erickson were 21.3 and 21.6 cm, respectively. AWC was 0.18 cc/cc for the loam and SiCL textured parent materials. On the high lime till soils, the AWC to 1.2 m were 17.2 cm or more. Bulk density (105°C) of the material below 60 cm varied from 1.71 to 1.99 for the Aneda and Inwood soil presented. AWC of the different textures in the subsoil below 60 cm varied from 0.09 to 0.15 cc/cc.

A comparison of the AWC on a typical Plum Ridge (which grades coarser with depth) and the Plum Ridge silty variant of the subsoil had AWC to 1.2 m of 9.0 and 18.9 cm, respectively. AWC of similar textures within the profiles varied depending on the subsoil characteristics; the VFS strata had an AWC of 0.03 cc/cc in the typical soil and 0.17 in the silty variant.

Infiltration rates for soils on the upland tills, high lime till and high lime lacustrine deposits were variable; generally the better drained soils had higher infiltration rates. Cultivated soils with shallow A horizons and a Bt or Btj had variable and generally lower infiltration rates, presumably due to some compaction by tillage practices.

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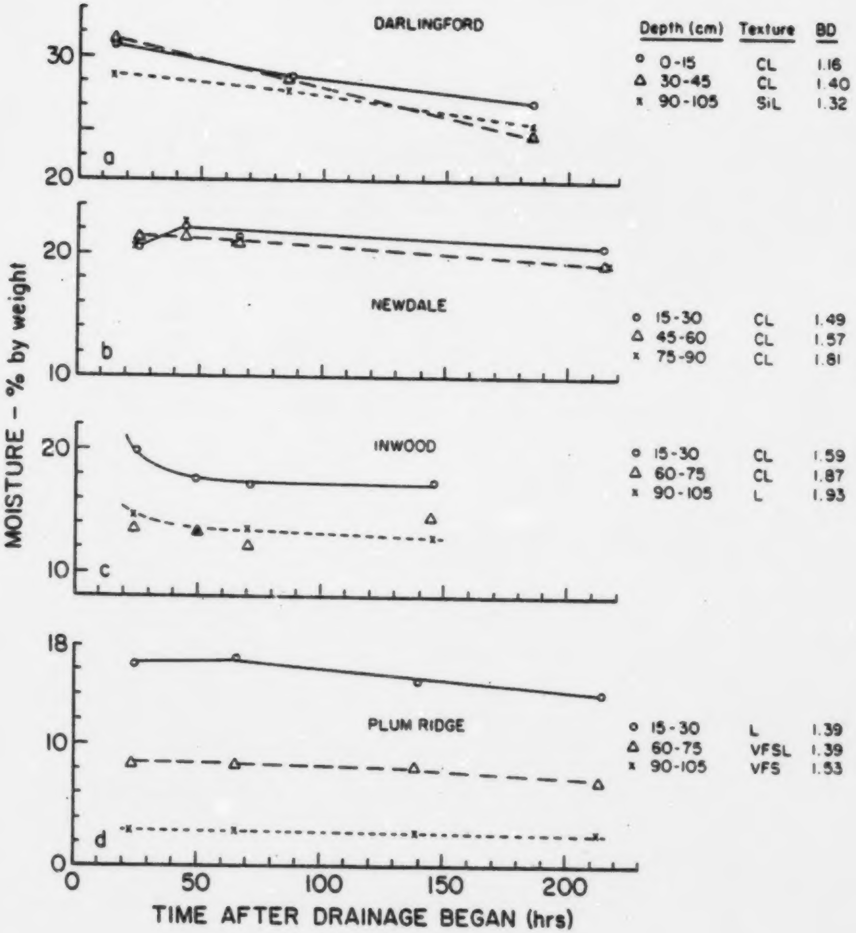


Figure 1. Percent soil water by weight versus time (hours) after drainage began for a) Darlingford, b) Newdale, c) Inwood, and d) Plum Ridge soils.

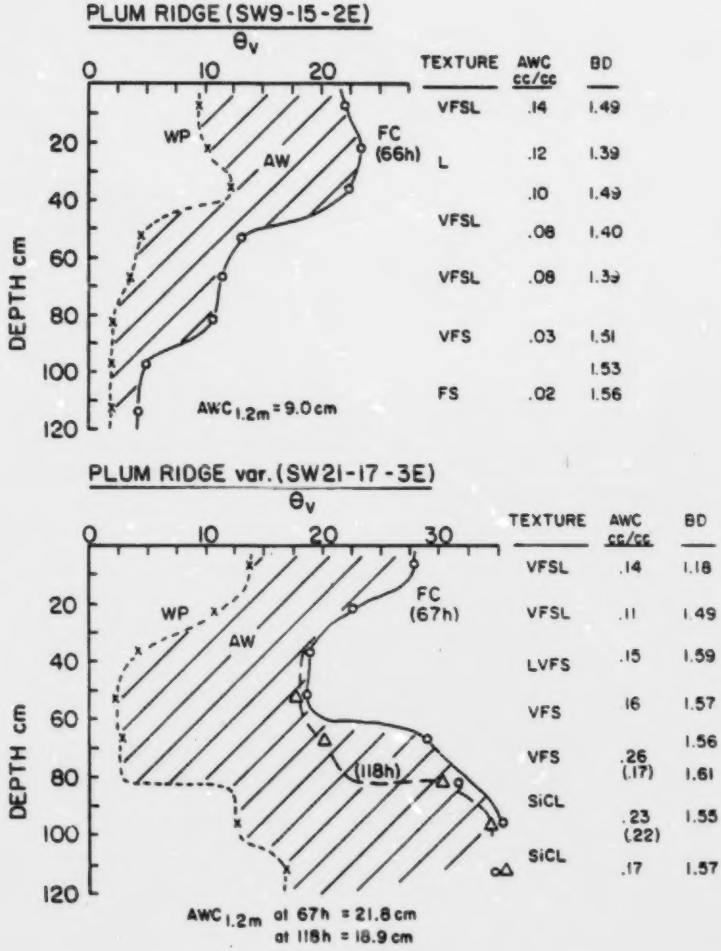


Figure 2. Field capacity, texture, available water capacity and bulk density of a Plum Ridge soil (a) and Plum Ridge variant with finer subsoil (b). (very strongly to extremely calcareous lacustrine sediments).

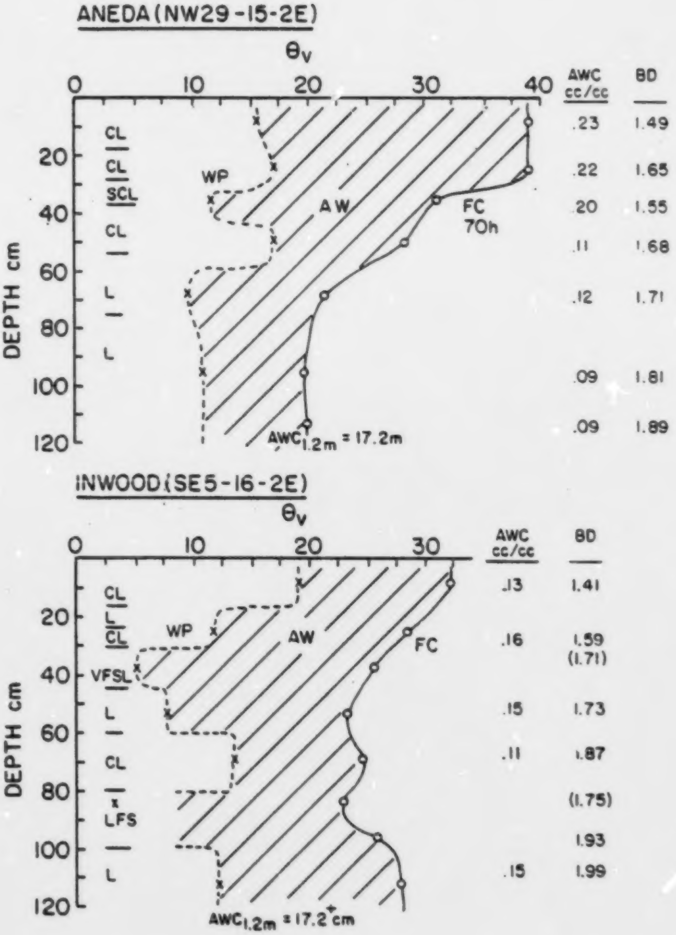
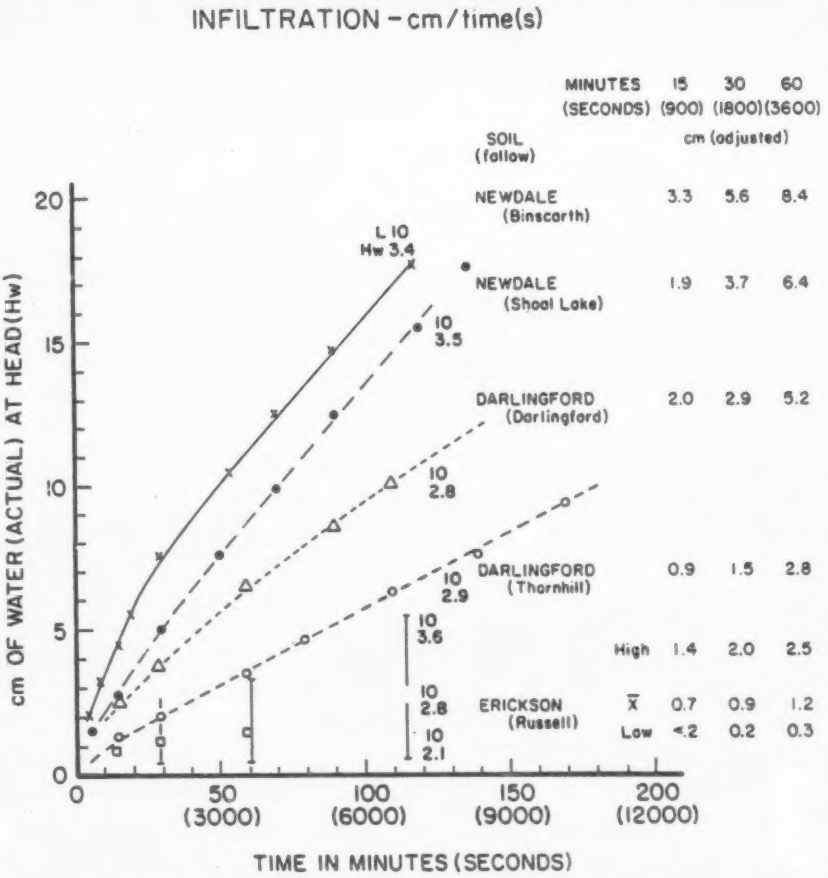
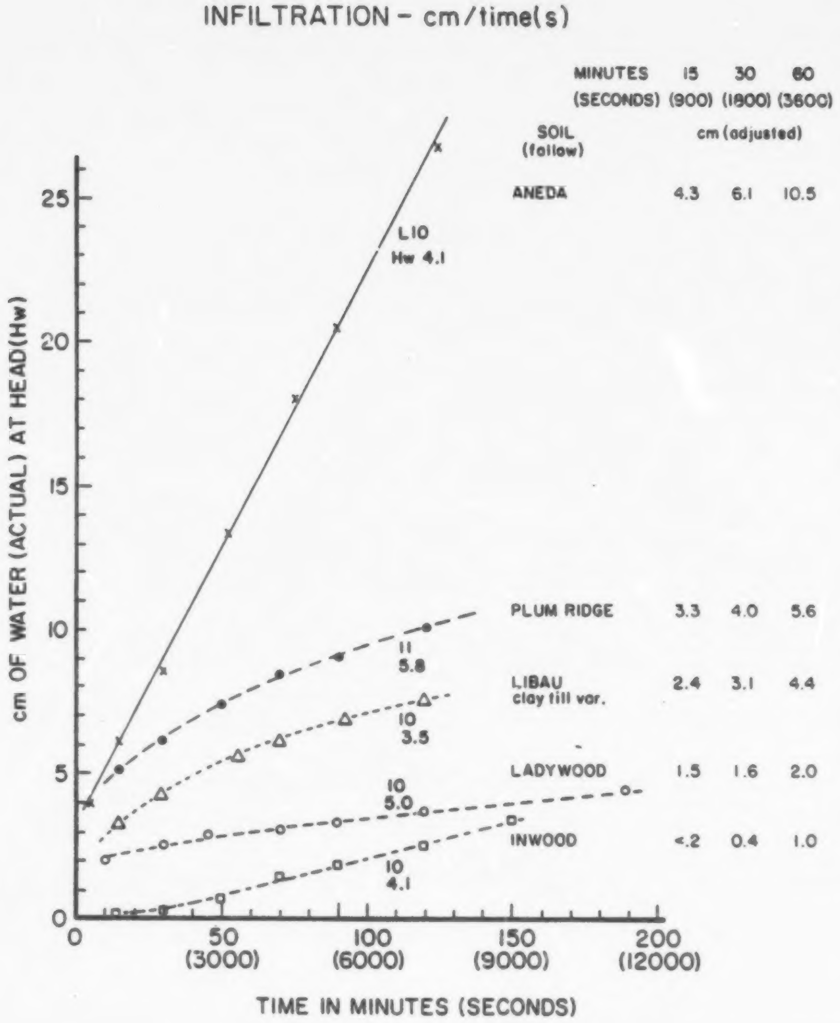


Figure 3. Field capacity, texture, available water capacity and bulk density of Aneda (a) and Inwood (b) soils (on high lime tills).



SOIL (fallow)	MINUTES (SECONDS)	15 (900)	30 (1800)	60 (3600)
		cm (adjusted)		
NEWDALE (Binscarth)		3.3	5.6	8.4
NEWDALE (Shoal Lake)		1.9	3.7	6.4
DARLINGFORD (Darlingford)		2.0	2.9	5.2
DARLINGFORD (Thornhill)		0.9	1.5	2.8
ERICKSON (Russell)	High	1.4	2.0	2.5
	$\overline{X}$	0.7	0.9	1.2
	Low	<.2	0.2	0.3

Figure 5. Infiltration rate expressed as cumulative cm of water with time (seconds) for the Darlingford, Erickson and Newdale Soils



SOIL (fallow)	MINUTES (SECONDS) 15 (900)	30 (1800)	60 (3600)
	cm (adjusted)		
ANEDA	4.3	6.1	10.5
PLUM RIDGE	3.3	4.0	5.6
LIBAU clay till var.	2.4	3.1	4.4
LADYWOOD	1.5	1.6	2.0
INWOOD	<.2	0.4	1.0

Figure 6. Infiltration rate expressed as cumulative cm of water with time (seconds) for the high lime till soils of the Aneda, Inwood, Liba (clay till variant), and coarse silty Plum Ridge and Ladywood lacustrine soils.

DEVELOPMENT OF AN INTERPRETIVE CLASSIFICATION SYSTEM FOR ASSESSING THE IRRIGATION SUITABILITY OF SOILS*

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INTRODUCTION

The rapid increase in the use of mobile sprinkler irrigation systems on the Canadian prairies in the late 1970's and early 1980's focused renewed interest by the PFRA organization on the procedures for evaluating the suitability of soils for irrigation. Technological advances in irrigation methodology had rendered many of the class limits of the 1964 classification system obsolete. In addition, each province was using a different modification of the 1964 system for rating soil suitability for irrigation. This lack of uniformity created difficulties for inter-provincial correlation of maps and soil data interpretation.

In 1981, PFRA convened a meeting in Saskatoon which brought soils, engineering, economics, and irrigation people together to discuss the status and adequacy of the procedures for classifying irrigation suitability. As a result of this meeting, a working group was established to review the existing procedures and to propose standard guidelines for evaluating irrigation suitability for application to all of the prairies. In early 1982, the working group was put under the auspices of the Land Resource Research Institute with the following mandate:

1. To revise, as required, the soil suitability rating system for irrigation to meet the regional needs of PFRA as well as other irrigation applications, and

2. To provide a standardized methodology and guidelines for rating irrigation suitability.

REQUIREMENTS

The working group decided that a standardized Irrigation Suitability Classification (ISC) system for soils should utilize soil survey data or data that can be obtained through standard routine soil survey procedures. The group also decided that to be widely applicable the ISC should be interpretive and independent of map scale and irrigation methodology. In addition, it should be designed in an appropriate manner suitable for computerization.

CRITERIA

The most important criteria for determining the irrigation suitability of soils are those factors which affect the acceptance, retention, and transmittance of water into and through the soil. These factors can be divided into two general categories: soil and landscape.

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* Presented to the 28th annual meeting of the Manitoba Soil Science Society, Jan. 9, 1985, Wpg.

The soil features that affect irrigability include the physical, morphological and chemical properties. Many of these properties are routinely observed and measured (or estimated) in the field. These properties are the basis on which the soils are described and characterized and are commonly included in tables and generalized soil descriptions in all soil survey reports. A listing of the pertinent soil features including a relative ranking of the criteria is presented in Table 1.

The landscape features pertain mainly to the geomorphology and condition of the land surface such as slope, relief, stoniness, etc. These properties are normally provided both on the soil map and in the soil description section of the report. Topographic landscape characteristics can also be obtained from air photographs and on-site inspections in those cases where it is not provided in the soil report. A list of pertinent landscape features including a relative ranking of the criteria is presented in Table 2.

METHODOLOGY

The approach used to develop this revised methodology includes some basic assumptions. For example, since it deals only with soils and landscapes criteria, it is not a complete irrigability rating system.

The ISC system does not consider agronomy, engineering, land tenure, management, markets, water availability, field shape or size, land development costs, transportation, or economics, all of which must be evaluated before a decision is made whether to irrigate.

Secondly, the new ISC focuses on the concept of limiting factors. This means that the rating assigned to a soil or field unit is determined by the factor(s) that would most adversely affect development and management of an irrigation system. The severity of the limitation determines the class; the nature of the limitation determines the subclass; both are used to designate the irrigation suitability land class.

Thirdly, the proposed ISC system is interpretive. Soil and landscape data must be available or obtained before it can be interpreted and ranked according to the guides provided in Tables 1 and 2.

GENERAL OUTLINE

The irrigation suitability classification system is based on 4 classes of soil limitations and 4 categories of landscape limitations (Table 3). Soil limitations are identified by the numbers 1 to 4 according to increasing severity of limitation (Table 1). Similarly, landscape limitations are identified using the symbols A, B, C and D according to their increasing severity of limitation (Table 2). The relative limitation ratings for both soils and landscapes were then combined into a matrix format resulting in a total of sixteen possible irrigation land class-categories (Table 4). Each of these land classes can be defined in terms of limitations due to soil factors, landscape factors or a combination of both (Table 5). All of these land classes fall into 4 general suitability groups defined as excellent, good, fair, and poor (Table 6).

This new irrigation suitability classification system correlates well with the systems presently in use in each of the three prairie provinces (Table 7). In some cases, the symbology of the new system is somewhat simpler and more informative than that presently in use. The symbology of the new system will always consist of a minimum of two characters. The numbers 1, 2, 3, or 4 which identify the increasing severity of soil limitations, appears first. The letters A, B, C, and D (upper case) which identify landscape limitations are indicated second. The specific limitation(s) may be indicated by using at least one and no more than three lower case symbols from Tables 2 and 3 as a third, fourth, and fifth component of the suitability rating.

e.g. 2Ad - slight limitation due to structure

3Bswp - moderate limitation due to salinity and wetness and a slight stoniness limitation

4Dmt2 - severe limitations due to low water holding capacity and steep complex slopes

APPLICATION

The new irrigation suitability system is presently in the final draft stages. It is planned to have several test applications, preferably one or two in each province in 1985. This testing process will help to develop the application procedures as well as evaluate the relevance of the criteria as presently proposed.

The method of application of this new system involves the following steps:

1. Identify the area to be evaluated
2. Identify all of the soil types
   - compile and compare the available information (corresponding to Tables 1 & 2) for each of the soils and the associated landscape features
3. Determine the severest rating for each soil and landscape property and using the matrix Table 4, determine the most appropriate soil or land class rating
4. Indicate the specific nature of the most limiting factor(s) using lower case symbols attached to the land class symbol.

This soil suitability rating is the first approximation of the irrigability of the land. If, at this point, the land suitability rating is too poor to consider irrigation, there may be no need for further evaluation of the other factors previously identified. Examples of general criteria rankings which may preclude further irrigability evaluation are presented in Table 8.

The application of these upper limits to specific sites may vary, however, depending upon the type of crop to be grown, the type of irrigation system used, etc.

ADVANTAGES

One of the advantages of the new system is that soil and landscape properties can be scanned and quickly compared to the guide tables.

This eliminates the need to do tedious calculations to arrive at a basic soil rating which was the approach in the previous system.

The system is easy to use. The nature and severity of the limiting factors are highlighted in the new system. This approach identifies potential management problems connotatively and facilitates further analysis and evaluation as to the feasibility of overcoming or ameliorating the type and/or severity of the limitation.

This system should be equally useful in the field as well as in the office. It identifies the properties that need field inspection and provides a relative ranking as to their severity. The final irrigability decision, however, must be made on a site by site or project by project basis after due consideration has been given to all the other irrigation-related non-soil factors.

ACKNOWLEDGEMENTS

Most of the credit for developing this approach to assessing irrigation suitability must go to the members of the Working Group which includes: J. Ellis, D. Anderson - S.I.P., A. Bristol - S.D.A., W. Nicholiachuk - Env. Can. & CDA, and L. Chambers - PFRA, Saskatchewan, W. Pettapiece - Ag. Can., S.S., and K. Pohjakas - ADA, Alberta. Sincere appreciation is also extended to the many other people who took time to review the various drafts of the system and make constructive suggestions.

Table 1. Soil Features Affecting Irrigation Suitability

Degree of Limitation / Soil Feature "Symbol"	1 None	2 Slight	3 Moderate	4 Severe
	'PERMANENT' SOIL FEATURES			
Texture (Classes)*	L, SiL, VFSL, FSL	CL, SiCL, SCL, FSCL, SL, LVFS	C, SC, SiC, CoSL, VFS, LS	HvC, LCoS, CoS, S, Gr
(Groups)	Medium	Moderately Fine Moderately Coarse	Fine Coarse	Very Fine Very Coarse
Structure "d"	Granular Single Grained Subangular-blocky	Platy Blocky Prismatic	Columnar Massive	
A.W.H.C. (mm/1.2m) "m"	>120	120-60	60-30	<30
K-Sat. (mm/hr) 0-1.2m "k1"	50-15	15-5 150-50	5-1.5 500-150	<1.5 >500
1.2-3m "k2"	>15	15-5	5-1.5	<1.5
Geological Uniformity 0-1.2m "g1"	1 Text. Class	2 Text. Classes coarser below	2 Text. Classes finer below. 3 Text. Classes coarser below	3 Text. Classes finer below
1.2-3m "g2"	2 Text. Classes	3 Text. Classes coarser below	3 Text. Classes finer below	
Depth to Bedrock (m) "r"	>3	3-2	2-1	<1
Intake Rate (mm/hr) "q"	>15	15-5	5-1.5	<1.5
	'NON-PERMANENT' SOIL FEATURES			
Drainage Class "w"	Well, moderately well, rapid, excessive	Imperfect		Poor Very Poor
Depth to Water Table (m) "h"	>2	2-1.2 (if salinity is problem)		<1.2
Organic Matter % *	>2	1-2		<1
Salinity (dS/m) (m) "S1" 0-.6	<2	2-4	4-8	>8
"S2" .6-1.2	<4	4-8	8-16	>16
"S3" 1.2-3	<8	8-16	>16	
Sodicity (S.A.R.) (m) "n1" 0-1.2	<6	6-9	9-12	>12
"n2" 1.2-3	<6	6-9	9-12	>12

* No symbol is proposed for texture or organic matter. Both organic matter and texture will not be identified as a subclass limitation, but rather the associated features such as AWHC, K-Sat., etc. O.M. is important in assessing crusting and erosion.

Table 2. Landscape Features Affecting Irrigation

Degree of Limitation Landscape Features "Symbol"	A None	B Slight	C Moderate	D Severe
Slope (%) "t1" (simple)	<2	2-10	10-20	>20
"t2" (complex)		<5	5-15	>15
Av. Local Relief (m) "e"	<1	1-3	3-5	>5
Stoniness Class(es) (% Cover) "p"	0,1,&2	3	4	5
Inundation (Freq.) (Flooding) "i"	1:10	1:5	1:1 Annual (spring)	Seasonal 1:<1
"c" Potential Impact on non-target, non-irrigated areas	none	low	medium	high
Horizontal Variability of Infiltration "v"	very low	low	medium	high

Table 3. Factors Affecting Irrigation Suitability

Criteria	Degree of Limitation			
	Non	Slight	Moderate	Severe
Soil	1	2	3	4
Landscape	A	B	C	D

Table 4. Methodology for Determining Irrigation Land Classes

Suitability Rating		Excellent	Good	Fair	Poor
Soil Limitations Landscape Limitations		None 1	Slight 2	Moderate 3	Severe 4
		Irrigation Land Classes			
None	A	1A	2A	3A	4A
Slight	B	1B	2B	3B	4B
Moderate	C	1C	2C	3C	4C
Severe	D	1D	2D	3D	4D

Table 5. Definition of Individual Irrigation Land Classes

Irrigation Suitability Rating - Excellent

Class	Description
1A	Lands have no internal or external features which limit or restrict their use for irrigation
	Irrigation Suitability Rating - Good
2A	Lands have slight limitations for irrigation due to unfavorable soil characteristics
1B	Lands have slight limitations for irrigation due to unfavorable landscape characteristics
2B	Lands have slight limitations for irrigation due to a combination of both soil and landscape characteristics
	Irrigation Suitability Rating - Fair
3A	Lands have moderate limitations for irrigation due to adverse soil characteristics
3B	Lands have moderate limitations for irrigation due to adverse soil characteristics and a slight limitation due to unfavorable landscape characteristics
3C	Lands have moderate limitations for irrigation due to a combination of adverse soil and landscape characteristics
1C	Lands have moderate limitations for irrigation due to adverse landscape characteristics
2C	Lands have moderate limitations for irrigation due to adverse landscape characteristics and slight limitations due to unfavorable soil characteristics
	Irrigation Suitability Rating - Poor
4A	Lands have severe limitations for irrigation due to deficient internal soil characteristics
4B	Lands are poor for irrigation due to severe limitations of internal soil conditions and slight limitations due to landscape characteristics
4C	Lands are poor for irrigation because of severe internal soil limitations and moderate landscape limitations
4D	Lands are poor for irrigation because of severe soil and landscape limitations
1D	Lands are poor for irrigation because of severe landscape limitations
2D	Lands are poor for irrigation because of severe landscape limitations and slight soil limitations
3D	Lands are poor for irrigation due to severe landscape limitations and moderate soil limitations

Table 6. General Descriptions of Irrigation Land Classes

Irrigation Land Classes	Suitability Rating	Description
1A	Excellent	Lands in this class have no significant limitation(s) for irrigation. Lands in this class are capable of producing a sustained and relatively high yield of a wide range of climatically adapted crops. The soils are medium textured, well drained, and hold adequate available moisture. Harmful accumulations of soluble salts are absent from the soil and topography is level to nearly level. These lands are generally considered to be irrigable.
2A 2B 1B	Good	Lands in these classes have slight limitations for irrigation due to unfavorable characteristics of either the soil or landscape or both. A narrower range of crops or slightly more input to development and management may be required. They can be maintained or possibly improved with proper management. The soils in these classes may be heavier or lighter in texture than soils in Class 1A. The specific factor(s) limiting irrigation use of these lands is designated by connotative lower case symbol(s) following the land class symbols.
3A 3B 3C 1C 2C	Fair	Lands in these classes have moderate limitations for irrigation use due to deficient characteristics of either the soil, the landscape or a combination of both. The soils may be inferior because of excess salinity, sodicity, very low hydraulic conductivity or low water holding capacity. The specific factor(s) limiting irrigation utilization of these lands will be designated by connotative lower case symbol(s) following the land class symbols. Greater management input as well as more intensive soil conservation and improvement practices are required for this group of soils than for the soils in the good category.
4A 4B 4C 4D 1D 2D 3D	Poor	Lands in these classes have severe limitations for irrigation use due to adverse characteristics related to either the soil, the landscape or a combination of both. These lands may have some limited use under irrigation but generally their limitations are so severe that they do not form suitable irrigation-farm units. Special crops, irrigation system designs, and special soil and water management practices will be required to irrigate any lands in this category. In general these lands are considered to be restricted or unsuitable for sustained irrigation use.

Table 7. Correlation of New Ratings with Approximate Equivalent Ratings Presently used in each of the three Prairie Provinces

	Approximate Equivalent Rating		
New Rating	Alberta	Saskatchewan	Manitoba
1A	$1\ \frac{ST}{11}$	1	1
2A	$2\ \frac{ST}{21}$	2	2S
1B	$2\ \frac{ST}{12}$	-	2T
2B	$2\ \frac{ST}{22}$	2	2ST
3A	$3\ \frac{ST}{31}$	3	3S
3B	$3\ \frac{ST}{32}$	3	3ST
3C	$4\ \frac{ST}{33}$?	3	3ST
1C	$4\ \frac{ST}{13}$?	-	3T
2C	$4\ \frac{ST}{23}$?	-	3TS
4A	$5\ \frac{ST}{41}$?	4	4S
4B	$5\ \frac{ST}{42}$? $6\ \frac{ST}{42}$?	4	4ST
4C	$5\ \frac{ST}{43}$? $6\ \frac{ST}{43}$?	4	4ST
4D	-	4	4ST
1D	$6\ \frac{T}{4}$	-	4T
2D	-	-	4TS
3D	-	-	4TS

Table 8. Ranking of Major Limiting Factors

The following list identifies the major factors in order of priority of interpretation. Once the factor limitation becomes severe there is no need to proceed further with additional ratings. The ranking is based on the sequence of visual inspection first followed by on-site inspection, sampling, measuring and evaluating. If none of these criteria receive a severe rating, a detailed irrigation suitability rating should be made.

1. Topography - if simple slopes exceed 20% - rating is severe
   - if complex slopes exceed 15% - rating is severe
   - if local relief exceed 5 meters - rating is severe
2. Drainage - if drainage is poor to very poor - rating is severe
3. Flooding - if seasonal - rating is severe
4. Stoniness - if Class 5 - rating is severe
5. Salinity - if surface salinity exceeds 8 mS/cm - rating is severe
   - if subsurface salinity exceeds 16 mS/cm - rating is severe
   - if sodicity (SAR) exceeds 12 - rating is severe
6. Texture - if HVC, LCoS, CoS, S, Gr - rating is severe
   (K Sat. is too high or too low)
   (AWHC is too low)
   (Intake rate is too low)
7. Depth to water table - if less than 1 meter - rating is severe
8. Depth to bedrock - if less than 1 meter - rating is severe
9. Geological Uniformity- if subsoil is 3 textural classes finer than surface - rating is severe
10. Affect on adjacent area - if potential is high - rating is severe

NOTE: Some of these criteria may be overcome by engineering technology if deemed economical. However, it is assumed that this would only apply to specific situations rather than the general case.

PRELIMINARY RESULTS OF SOIL CLIMATE AND HYDROLOGY STUDIES IN THE DISCONTINUOUS PERMAFROST ZONE NEAR THOMPSON, MANITOBA

G.F. Mills, H. Veldhuis and R.G. Eilers

Canada-Manitoba Soil Survey

ABSTRACT

Field studies of two toposequences established to monitor soil temperature, permafrost and hydrology in relation to soil morphology and associated vegetation are described. Preliminary observations on fluctuation in soil temperature, depth to water table, distribution of permafrost and thickness of active layer are presented.

INTRODUCTION

Two benchmark sites, each consisting of a toposequence of soils developed on fine textured lacustrine sediments, have been established to characterize soil and vegetation conditions and monitor soil thermal and moisture relations in the Thompson clay belt of northern Manitoba. The project has several emphasis, among which are the study of relationships between soil climate and soil classification, and soil climate and hydrology in landscapes containing permafrost and the influence that vegetation cover has on these relationships. The first toposequence is characterized by mature coniferous vegetation typical of the northern boreal forest. A second toposequence with comparable slope and aspect was established in a recent burn area to monitor the effect of vegetation cover and peaty surface layers on soil climate and permafrost.

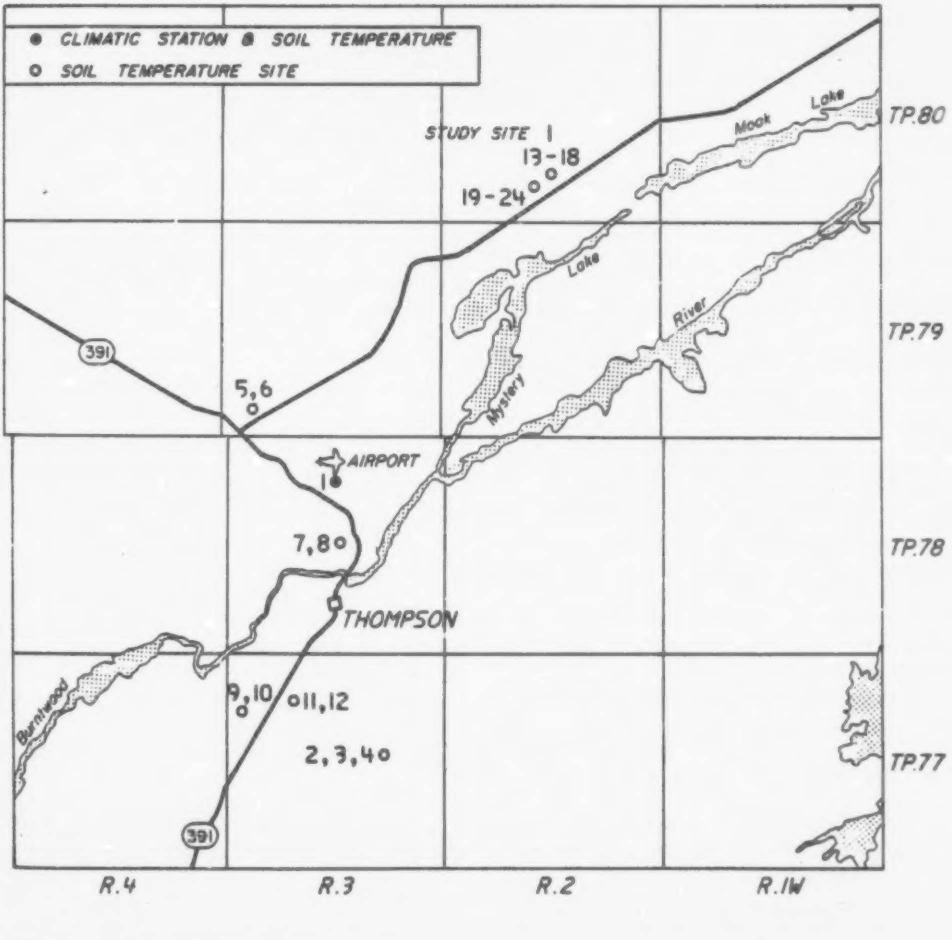
The objective of this paper is to present preliminary observations on fluctuation in soil temperature, water table, distribution of permafrost and thickness of active layer.

METHODOLOGY

The two benchmark sites are located 16.5 km northeast of Thompson along the Thompson-Split Lake highway in northern Manitoba at approximately lat. 55°54'N, long. 97°43W (Figure 1). Both toposequences are located on a gently sloping clayey lacustrine blanket with a north aspect. The study area occurs in the Nelson River Section of the Boreal Forest Region (Rowe, 1972) and is characterized by discontinuous permafrost (Brown, 1970).

Site Characteristics

Site 1 covers 2.25 ha (100 m x 225 m) and was characterized on a 25 m grid (Figure 2). Soil type, thickness of organic surface layer, depth to permafrost table (active layer) and vegetation type was determined at each grid point to enable mapping of the soils and permafrost distribution. Detailed topography within the study site was determined by levelling at 5 m intervals along each grid line.



● CLIMATIC STATION & SOIL TEMPERATURE
○ SOIL TEMPERATURE SITE
STUDY SITE 1
13-18
19-24
Mook Lake
Lake
Mystery
River
391
5,6
AIRPORT
1
7,8
THOMPSON
Burntwood
9,10
11,12
2,3,4
391
TP.80
TP.79
TP.78
TP.77
R.4
R.3
R.2
R.1W

Figure 1. Location of Study Area

Site 2 is located approximately 0.9 km west of Site 1, in a 17 year old burn area. The center line of this plot was also set out on a 25 m grid; soil type, site and vegetation characteristics were examined at each grid point. Topography along the center line was determined by levelling at 5 m intervals. Levels were also run between Site 1 and 2 to determine topographic relationships between the two plots.

Instrumentation and Monitoring

The center line (Transect C in Site 1 and Transect H in Site 2) was instrumented at grid points selected to represent the range of soil, hydrology and vegetation conditions in each site. Instrumentation consists of thermocouples and frost tubes to monitor soil temperature, permafrost and active layer characteristics. Shallow water table observation wells and piezometers were installed to study near surface hydrology conditions. The soil from each instrumentation site was described in detail and sampled for chemical and physical analysis. The plot layout for study site 1 and location of instrumentation is shown in Figure 2.

The monitoring program at the benchmark sites has been maintained by Manitoba Agriculture Soils and Crops staff at Thompson. Monitoring has been at monthly intervals during the growing season and less frequently (1 to 3 times) during the winter. Aerial climate data from Thompson were compiled to assist in the interpretation of soil climate-permafrost relationships observed in the study sites.

PRELIMINARY RESULTS AND DISCUSSION

Description of Study Sites

a) Site 1

The center line (Transect C) of this plot follows a toposequence descending from a gently sloping upland through a very gently sloping bog veneer terminating in a slightly raised peat plateau (Figure 3). Maximum relief is 2.5 m over the 225 m transect. The upland sites (C10 and C9) do not contain permafrost within 2 m of the soil surface whereas the bog veneer is characterized by discontinuous permafrost associated with non-frozen collapse or thaw areas. The peat plateau contains permafrost throughout.

From upper to lower topographic position the toposequence consists of the following soil types:

- The upland is characterized by dominantly Solonetzic Gray Luvisol soils with a small area of Orthic Luvic Gleysol at the toe of the slope.

- The bog veneer is characterized by Terric Organic Cryosols associated with Brunisolic Static Cryosols where the organic veneer is thin.

- Collapse areas in the bog veneer are non-frozen and characterized by very poorly drained Terric Fibrisol or Rego Gleysol peaty phase soils.

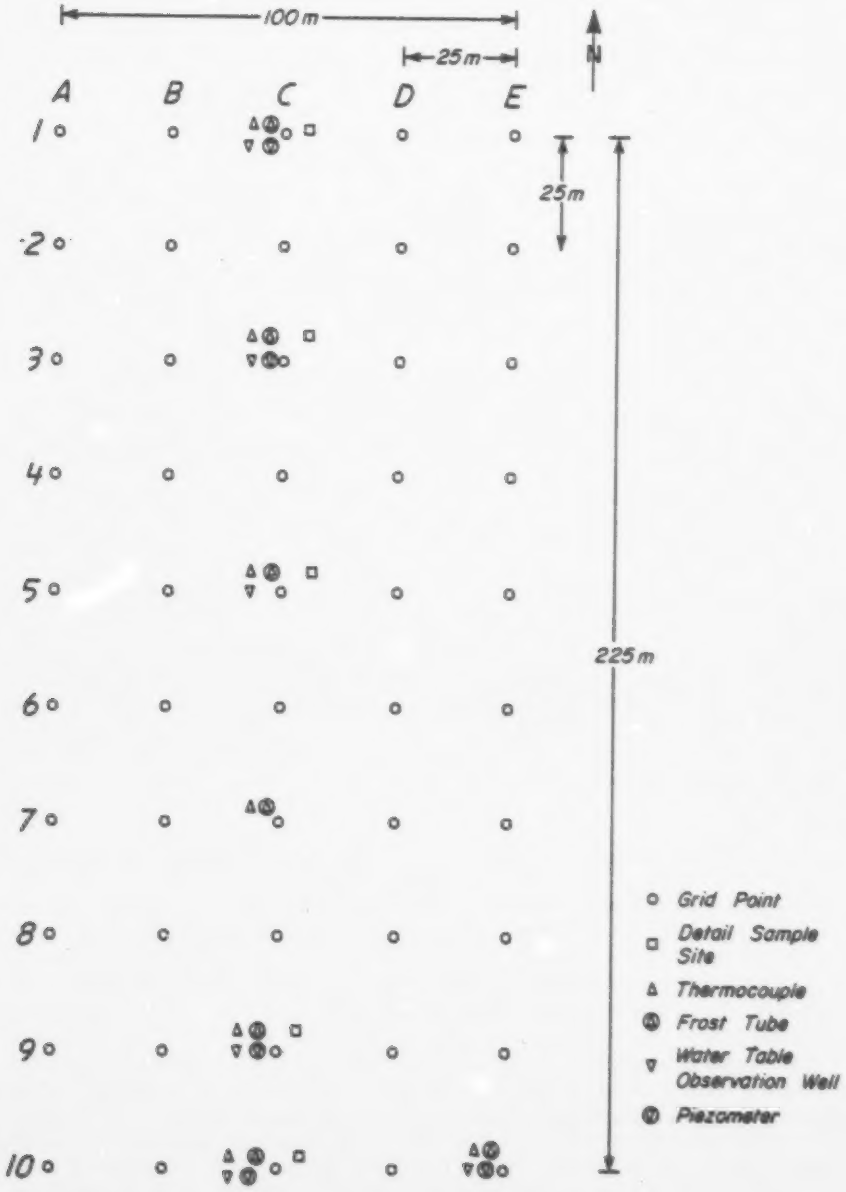

100 m
25 m
N
A
B
C
D
E
1
2
3
4
5
6
7
8
9
10
25 m
225 m
Grid Point
Detail Sample Site
Thermocouple
Frost Tube
Water Table Observation Well
Piezometer

Figure 2. Groundtruth and Instrumentation for Site 1

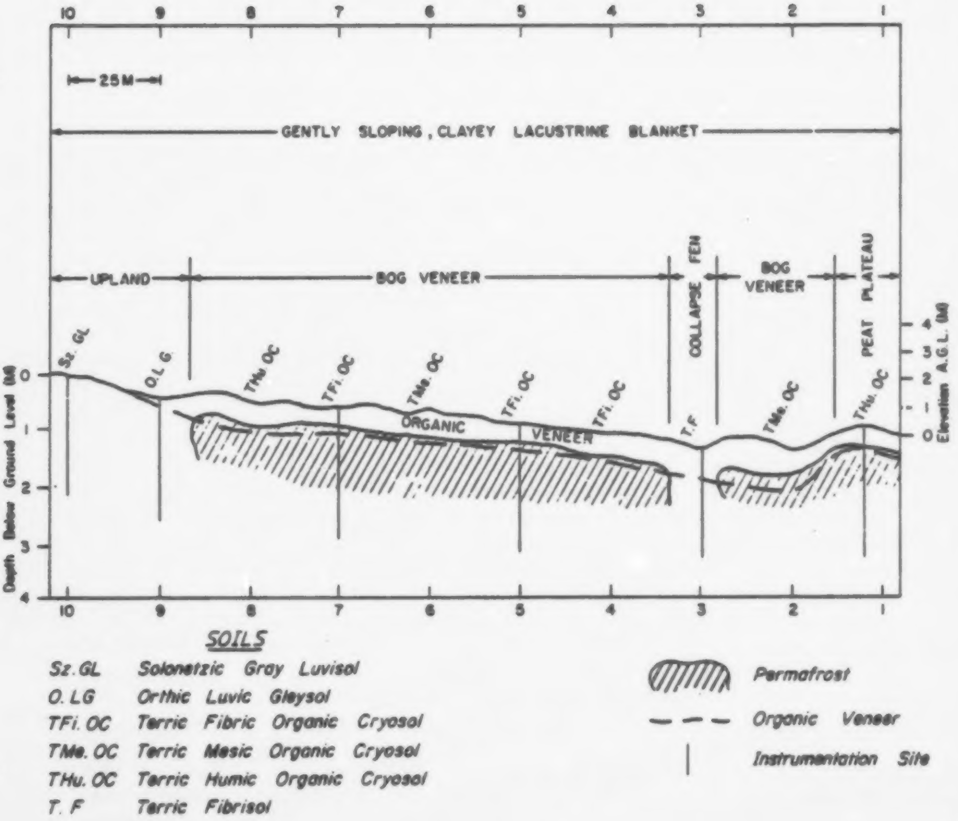

10 9 8 7 6 5 4 3 2 1
25M
GENTLY SLOPING, CLAYEY LACUSTRINE BLANKET
UPLAND
BOG VENEER
COLLAPSE FEN
BOG VENEER
PEAT PLATEAU
Sz. GL
O.L.G
THu. OC
TFi. OC
TMe. OC
TFi. OC
TFi. OC
T.F
TMe. OC
THu. OC
ORGANIC
VENEER
Depth Below Ground Level (M)
0
1
2
3
4
Elevation A.G.L. (M)
0
1
2
3
4
SOILS
Sz. GL Solonetzic Gray Luvisol
O. LG Orthic Luvic Gleysol
TFi. OC Terric Fibric Organic Cryosol
TMe. OC Terric Mesic Organic Cryosol
THu. OC Terric Humic Organic Cryosol
T. F Terric Fibrisol
Permafrost
Organic Veneer
Instrumentation Site

Figure 3. Cross-section along Transect C, Site 1

- The peat plateau is characterized by Terric Humic Organic Cryosol soils.

Soil drainage ranges from good to poor on the upland and imperfect to poor and very poor on the bog veneer. The peat plateau is moderately well to imperfectly drained.

Coniferous forest comprised of black spruce-ericaceae-mixed moss vegetation typical of central and northern portions of the Boreal Forest dominates the bog veneer and peat plateau and mixed jackpine and black spruce occur with occasional aspen on better drained portions of the upland.

b) Site 2

The center line of this plot descends through a gently sloping upland terminating in a bog which is very gently sloping to level. Maximum relief is 7 m over the 225 m transect. The upland sites (H10 to H6) slope at about 4.5% whereas Sites H5 to H3 occur on slopes of about 1.5%. Sites H2 and H1 are nearly level (Figure 4).

From upper to lower topographic position the toposequence consists of the following soil types:

- The upland is characterized by dominantly Solonetzic Gray Luvisol soils with a small area of Gleysol soils at the toe slope position.
- The organic terrain is characterized by Terric Humic Fibrisol soils and peaty phase Gleysolic soils where the surface peat is thin.

Soil drainage ranges from good to poor on the upland and poor to very poor in the organic terrain. Mixed coniferous-deciduous forest on the upland consists of young jackpine, black spruce, aspen and birch regeneration. Young black spruce, tamarack and occasional jackpine with swamp birch and willow understory and a mixed moss ground cover occur on the poorly drained mineral and organic soils

c) Comparison of Sites

Maximum relief in Site 2 (Transect H, Figure 4) is approximately 2.5 times greater than the maximum relief in Site 1 (Transect C, Figure 3). Comparison of the relative relief in Site 1 to that of Site 2 indicates the lowest point in Site 2 occurs at a higher elevation than the highest point in Site 1 (Figure 5). This means that drainage not only occurs from sites 10 to 1 in each transect, but drainage can also occur at all points from Transect H towards Transect C. The more gently sloping portion of Transect H (from Sites H5 to H1) compares with the maximum local relief and slope range encountered in Transect C. The elevation of Site H5 correlates in landscape position closely with Site C10. The surficial geology of both sites is similar as indicated by drill logs for the upper 3 to 4 meters. Site 1 is characterized by extensive permafrost and organic veneer whereas there is no permafrost in the second study site and the organic veneer is much less extensive.

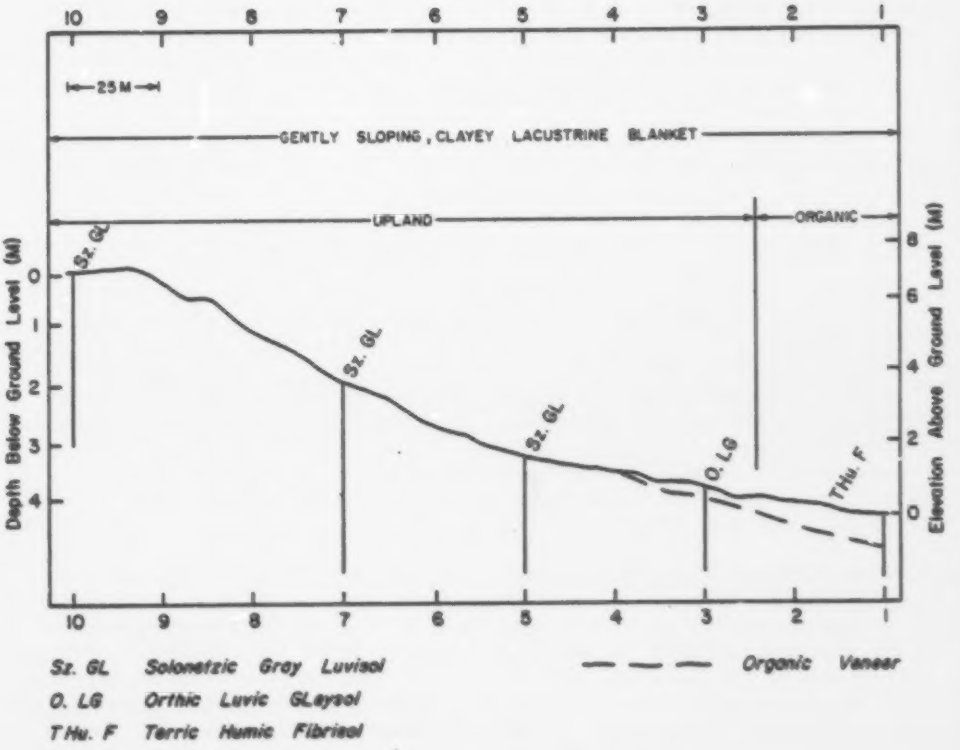

10
9
8
7
6
5
4
3
2
1
25 M
GENTLY SLOPING, CLAYEY LACUSTRINE BLANKET
UPLAND
ORGANIC
Depth Below Ground Level (M)
0
1
2
3
4
Elevation Above Ground Level (M)
8
6
4
2
0
Sz. GL
Sz. GL
Sz. GL
O. LG
THu. F
Sz. GL Solonetzic Gray Luvisol
O. LG Orthic Luvic GLeysol
THu. F Terric Humic Fibrisol
Organic Veneer

Figure 4. Cross-section along Transect H, Site 2

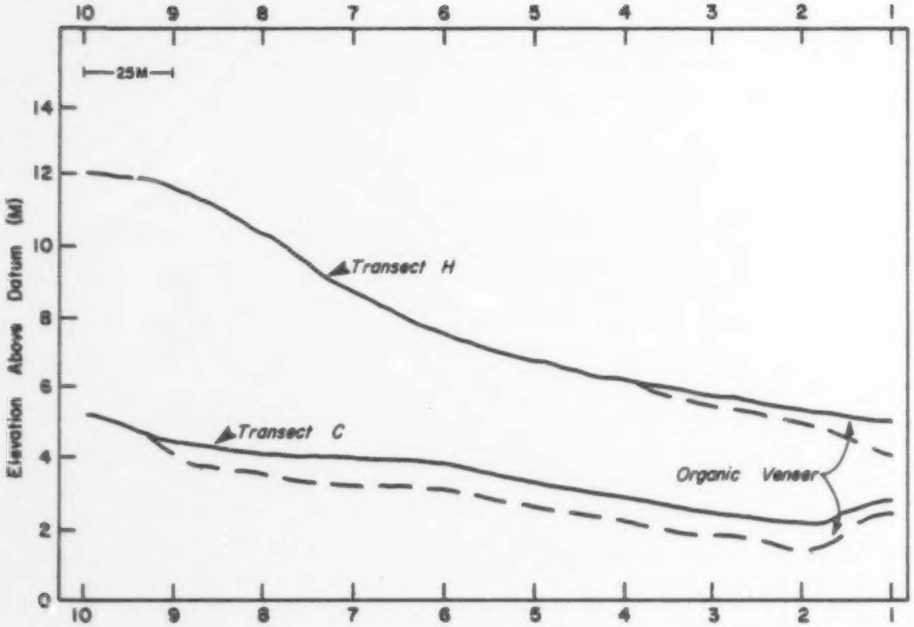


Figure 5. Elevations of Transects C and H

Climatic Characteristics of the Thompson Area

The climate in the Thompson area is characterized by short, warm summers and long cold winters. Mean annual air temperature is -3.9°C and total precipitation is 542 mm (Figure 6). Approximately 60% of the annual precipitation occurs as rain during the May to September period.

The weather at Thompson shows considerable annual variation from the long term normals recorded for the area. Recent weather data recorded for 1980 to 1984 are compared with the long term climatic normals in Figure 7. The annual variation from normal is summarized as follows:

1980 - warmer and wetter
1981 - much warmer and drier
1982 - colder and wetter
1983 - warmer and near average moisture
1984 - warmer and drier

Soil Climate and Permafrost Relations in Site 1

Long term soil temperature, soil moisture and permafrost properties are related to the average climate of the study area. Mean annual soil temperature and mean summer soil temperature determined from measurements at the 50 cm depth in well drained clayey textured soils in the Thompson area are 2.1°C and 4.5°C respectively (Mills et. al., 1977). Associated soils with poor drainage commonly have peaty surface layers which result in colder temperatures and the development of persistently frozen soil. Poorly drained, forested organic soils developed on deep peat commonly contain permafrost. Short term weather characteristics during the monitoring period have resulted in variation in these properties.

a) Soil Temperature

The fluctuation pattern of soil temperature follows seasonal trends in aerial climate. Greatest temperature fluctuation occurs near the soil surface and becomes much less at lower depths. Sites C10, C9 and C3 are the warmest soils in the Transect and do not contain permafrost (Figure 8, 9 and 11 respectively). In contrast, soils at Sites C5 and C1 are the coldest soils in the transect as evidenced by the occurrence of permafrost.

These relative differences in soil temperature affect soil morphology and biological activity in the soil. A soil temperature of 5°C is known as biologic zero. The length of time during which soil temperature exceeds 5°C is assumed to be the period of maximum biological activity. The lower temperatures of these soils retard root development and essential exchange and uptake processes required by plants to maintain active growth. Similarily soil temperatures below 5°C reduce microbiological activity, associated depletion of oxygen and development of reducing conditions. This temperature induced effect is noted in the dominance of high chroma soil colours and the absence of significant mottling in the soil descriptions for the transect (see Drill Log description in Figure 8-12. Gleyed morphology as indicated by dull colours and/or prominent mottles is not well expressed in soils where soil temperature does not rise above biologic zero. The length of time which the soils in Transect C are warmer than 5°C at the 20, 50 and 100 cm

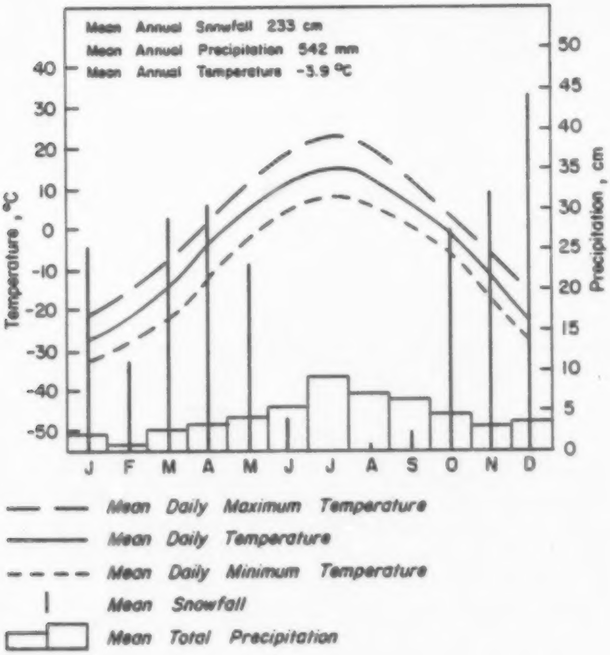


Figure 6. Climatic Characteristics, Thompson, Manitoba

Source: Canadian Climate Normals: Vol. 2
Temperature Vol. 3 Precipitation,
1951-1980. Atmospheric Environment
Service, Environment Canada

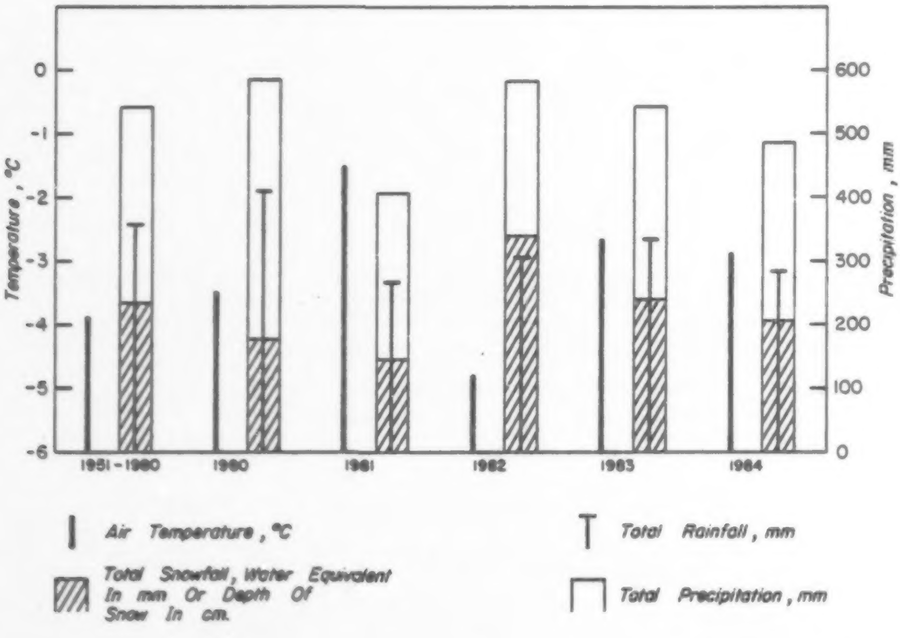


Figure 7. Comparison of Mean Climatic Data (1951-1980) with Annual Means for 1980 to 1984 at Thompson, Manitoba

depths is summarized in Table 1. All soils regardless of position in the transect appear oxidized with the exception of Site C3. Soil colours have 10YR hue with values ranging from 4 to 5 and chromas from 2.5 to 6. The soil at Site C3 has neutral colours and low chroma occurring immediately below the peaty surface layer but colours with higher hue and chroma occur below the 125 cm depth. Except for the soil colour at Site C3 none of the soils satisfy the colour criteria presently established to describe poor soil drainage (C.S.S.C., 1978).

b) Water Table

Water greatly influences the distribution and thermal regime of permafrost. In the discontinuous zone, the existence of permafrost is inhibited in poorly drained areas. Similarily, the presence of permafrost greatly influences the hydrological regime as the impermeability to water of the frozen soil alters both the movement of surface water and ground water.

The soils in Transect C at sites 10 and 9 do not have permafrost and are subject to water table fluctuations with high levels during the growing season and low levels during the period when the soil surface is frozen (Figure 8 and 9). The soil at Site C3 is not frozen but shows only minimal fluctuation in water table as it occurs at or above the organic soil surface throughout the year (Figure 11). Soil morphology at Site C3 indicates the effect of saturated conditions in the upper 70 cm of mineral soil but high chroma colour with no mottles occurs below 125 cm of the surface. In contrast, soils at Site C5 and C1 contain permafrost and have no permanent water table (Figure 10 and 12). Seasonal perched water levels from heavy rainfall and seepage from the non-frozen organic layer occur above the frost table at these sites.

c) Active Layer

Climate is a basic factor in the formation and existence of permafrost. Long term observations indicate a broad relation between mean annual air and ground temperatures in permafrost regions (Brown, 1970). Seasonal combinations of heat, rainfall and snowfall have a strong influence on fluctuation in soil temperature and the persistence of permafrost. As a result, the thickness of active layer (the surface layer of soil which thaws in summer and freezes in winter) in soils containing permafrost varies seasonally as well as from year to year.

The pattern of weather conditions through the fall, winter and spring "freeze" seasons and the nature of the subsequent summer "thaw" season affect distribution of frost and change in active layer. A heavy fall of snow in the autumn and early winter inhibits winter frost penetration. On the other hand, a thick snow cover that persists on the ground in the spring delays thawing of the underlying ground.

The weather conditions for 1980 to 1984 at Thompson are summarized according to seasons of heat loss (fall, winter and spring) and heat gain (summer or "thaw" season) in Table 2. Particular sequences of weather conditions appear to increase or decrease the extent of permafrost and the thickness of active layer. The annual fluctuation in thickness of active layer for Transects A, C and E in Site 1 measured in September of 1981 to 1984 is shown in Figure 13. These data indicate that since monitoring of the frost table was initiated, the number of

SCTC-1 Site C10 Solonetzic Gray Luvisol

DRILL LOG

Depth (cm)	Texture	Colour	Mottle Description			
			Abund.	Size	Contrast	Colour
10-50	C	-	-	-	-	-
50-70	C	10YR 4/3	-	-	-	-
70-100	C	10YR 5/6	-	(Gray Bodies)		10YR 4/2
100-150	C	10YR 4/4	-	-	-	10YR 4/3
150-200	C	10YR 4/4	few	fine	faint	7.5YR 5/6
200-250	C	10YR 4/3	many	fine	prominent	7.5YR 5/6
250-320	C	10YR 4/3	many	medium	prominent	10YR 6/8

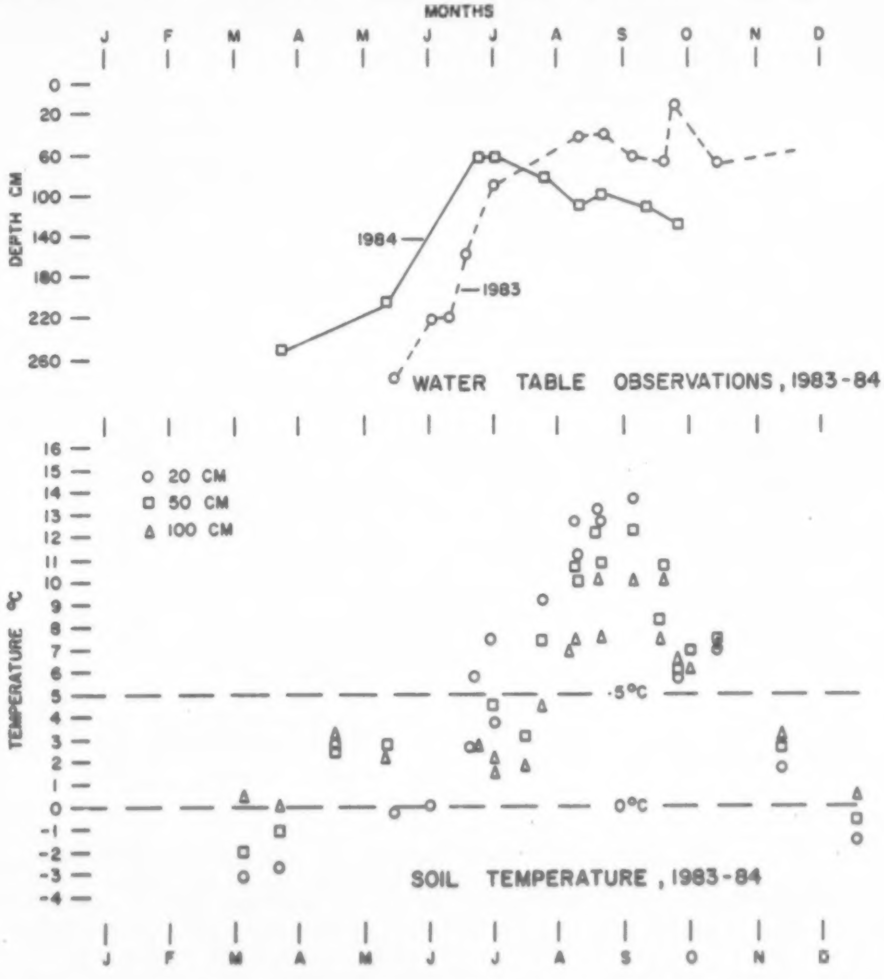
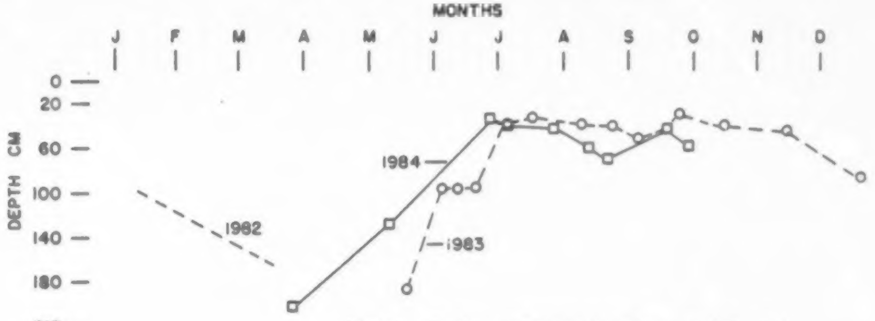


Figure 8. Drill Log, Water Table and Soil Temperature Observations for Solonetzic Gray Luvisol (Site C10)

SCTC-1 Ste C9 Orthic Luvic Gleysol

DRILL LOG

Depth (cm)	Texture	Colour	Mottle Description			
			Abund.	Size	Contrast	Colour
0-25	Organic	-	-	-	-	-
50-65	C	10YR 4/3	-	-	-	-
65-95	C	10YR 5/4	v. few	fine	faint	-
95-150	C	10YR 4/2.5	-	-	-	-
150-175	C	10YR 5/3	-	-	-	10YR 4/2
175-	C	10YR 5/4	few	medium	distinct	7.5YR 5/6



Water Table OBSERVATIONS, 1983-84

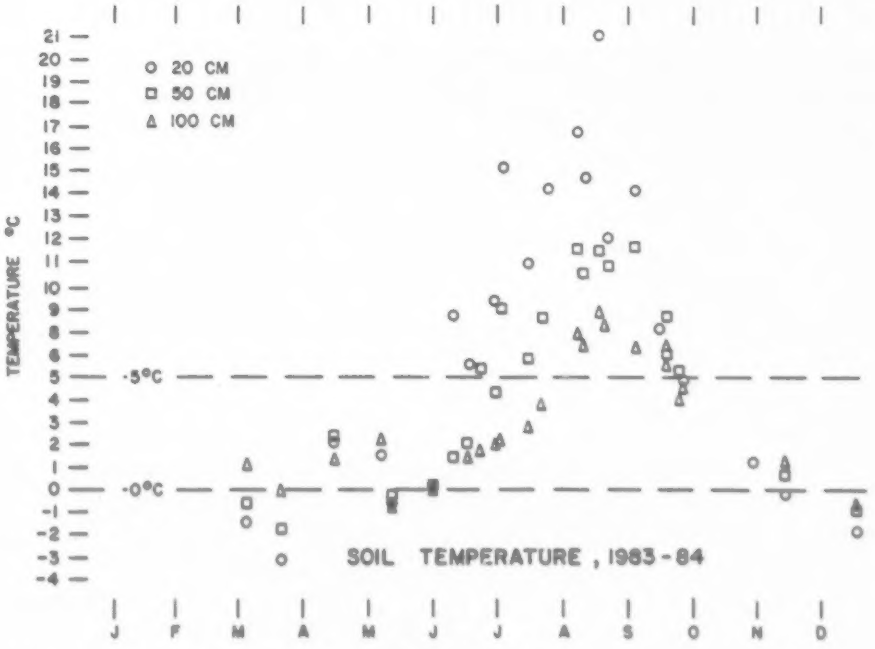
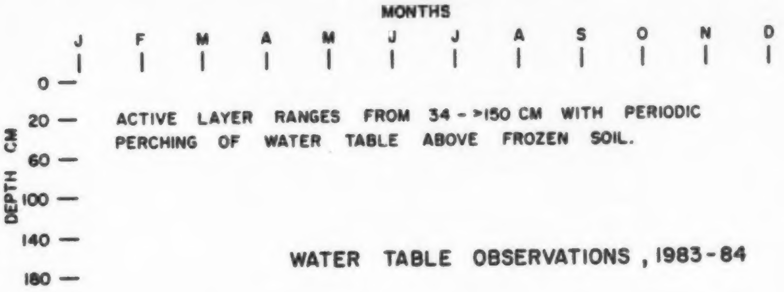


Figure 9. Drill Log, Water Table and Soil Temperature Observations for Orthic Luvic Gleysol (Site C9)

SCTC-1 Site C5 Terric Fibric Organic Cryosol

DRILL LOG

Depth (cm)	Texture	Colour	Mottle Description			
			Abund.	Size	Contrast	Colour
0-55	Organic	-	-	-	-	-
55-75	C	-	-	-	-	-
75-100	C	10YR 5/4	-	-	-	-
100-150	C	10YR 5/4	-	-	-	-
150-200	C	10YR 5/4	-	-	-	10YR 4/1
200-240	C	10YR 5/3	many	medium	faint	10YR 5/8-7.5YR 5/4
240-280	C	-	many	medium	prominent	7.5YR 4/4



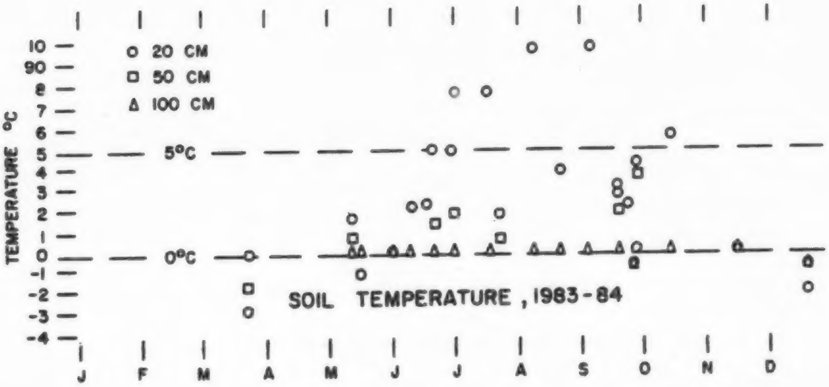
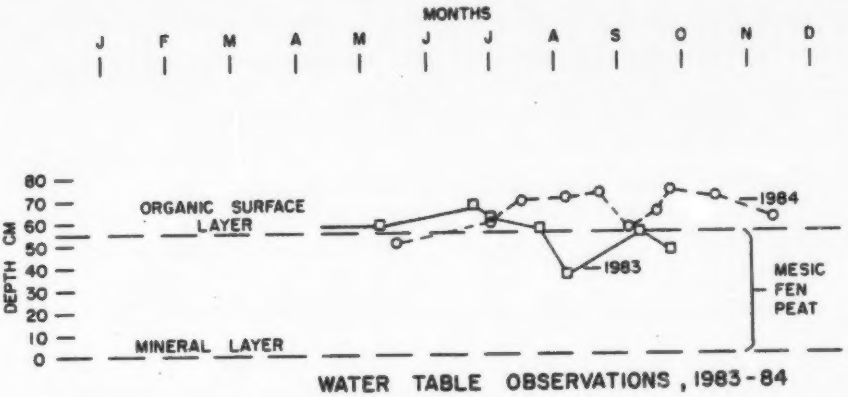


Figure 10. Drill Log, Water Table and Soil Temperature Observations for Terric Fibric Organic Cryosol (Site C5)

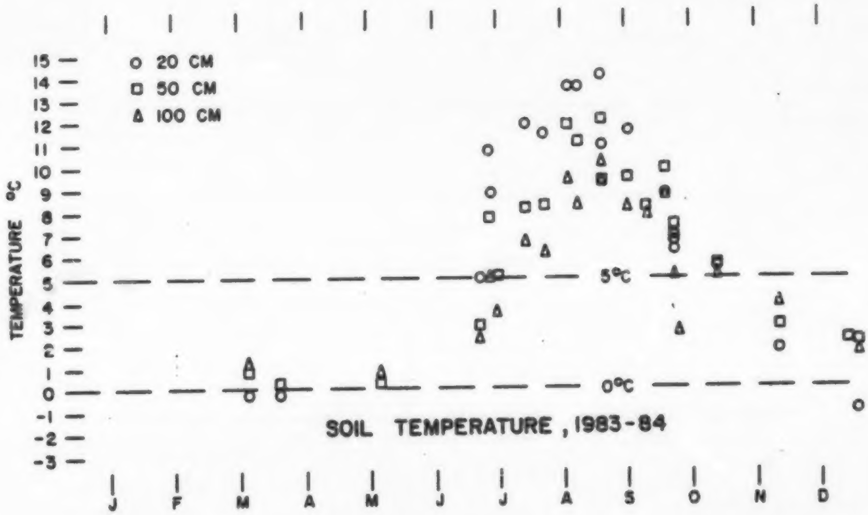
SCTC-1 Site C3 Terric Fibrisol

DRILL LOG

Depth (cm)	Texture	Colour	Mottle Description Abund.	Size	Contrast	Colour
0-55	Organic					
55-80	C	strongly gleyed below organic contact with with many medium distinct mottles				
80-100	C					
100-150	C	matrix colours become brown at 125cm				
150-200	C	high chroma brown, no mottles				
200-230	C	high chroma brown, no mottles				



WATER TABLE OBSERVATIONS, 1983-84



SOIL TEMPERATURE, 1983-84

Figure 11. Drill Log, Water Table and Soil Temperature Observations for Terric Fibrisol (Site C3)

SCTC-1 Site C1 Terric Humic Organic Fibrisol

DRILL LOG

Depth (cm)	Texture	Colour	Mottle Description			
			Abund.	Size	Contrast	Colour
0-30	Organic	-	-	-	-	-
55-75	C	5YR 4/2	few	fine	distinct	2.5YR 5/4
75-90	C	10YR 4/3	-	-	-	10YR 4/4
90-95	C	10YR 4/3	-	-	-	-
95-130	C	10YR 4/3	many	medium	distinct	10YR 4/6
130-175	C	-	-	-	-	-
175-200	C	10YR 4/3	few	medium	faint	10YR 4/2

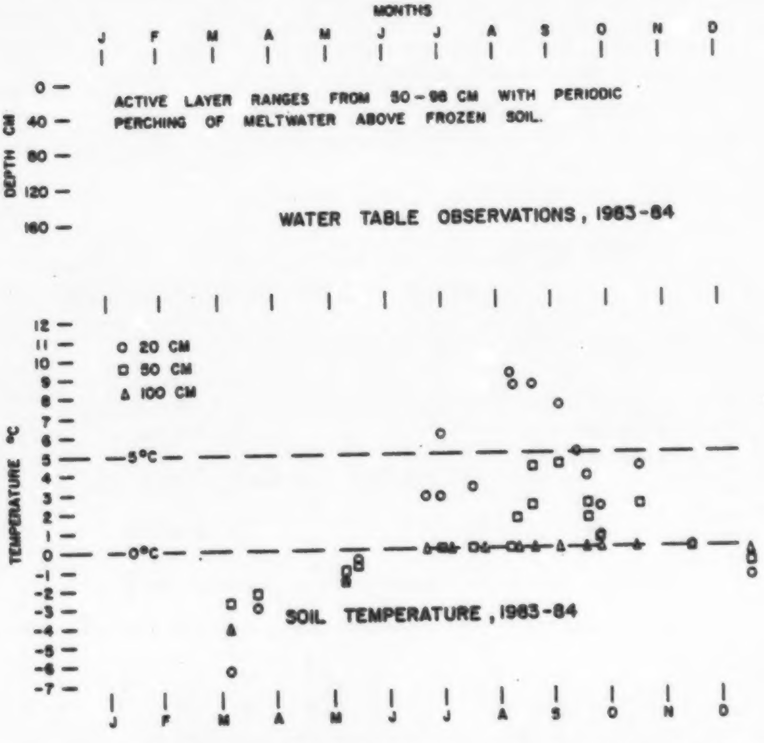


Figure 12. Drill Log, Water Table and Soil Temperature Observations for Terric Humic Organic Cryosol (Site C1)

Table 1. Time period and number of days soil temperature exceeds. $5^{o}C$

Site No. and Sub. group*	Depth of Organic	Depth in Soil, cm					
		20 cm		50 cm		100 cm	
		Period	Days	Period	Days	Period	Days
C10 Sz.GL	10	June 5-Oct. 21	138	June 27-Oct. 25	120	July 25-Oct. 25	92
C9 O.LG	25	May 21-Sept. 26	128	June 15-Sept. 26	103	July 20-Sept. 17	59
C5 TFi.OC	55	June 19-Sept.11	84	-	0	-	0
C3 T.F	55	June 21-Oct. 20	121	June 25-Oct. 20	117	June 25-Sept. 22	89
C1 THu.OC	30	June 25-Sept. 15	82	-	0	-	0

*Sz.GL	Solonetzic Gray Luvisol
O.OG	Orthic Luvic Gleysol
TFi.OC	Terric Fibric Organic Cryosol
T.F	Terric Fibrisol
THu.OC	Terric Humic Organic Cryosol

Table 2 Comparison of seasonal weather (1980-1984) to long-term climatic normals

Season	Time Period	Deviation from Normal
Winter	Oct. 1980-Apr. 1981	Warmer and drier
Summer	May 1981-Sept. 1981	Warmer and drier
Winter	Oct. 1981-Apr. 1982	Cooler and wetter
Summer	May 1982-Sept. 1982	Average temperature, drier
Winter	Oct. 1982-Apr. 1983	Warmer and wetter
Summer	May 1983-Setp. 1983	Warmer and wetter
Winter	Oct. 1983-Apr. 1984	Warmer and drier
Summer	May 1984-Sept. 1984	Average temperature, drier

sites containing frost has decreased and the depth of active layer increased.

Site 1 received an early, heavy, snowfall through September to December, 1982 followed by persistence of late spring snow into May, 1983. The winter of 1982-1983 was followed by a warmer, wetter than average summer which resulted in an increase from 31 to 35 sites with frost within 150 cm of the soil surface (Table 3). An increase in thickness of active layer occurred in 27 sites whereas a decrease in thickness of active layer occurred at 10 sites.

Below average snowfall in autumn 1983, and a warmer, drier winter period followed by above average spring snow and average summer temperature with drier conditions resulted in disappearance of frost from 12 sites by the fall of 1984 and a deepening of the active layer in 29 sites. During this time interval, the active layer decreased in thickness at 5 sites (Table 3).

d) Vegetation Effects

Vegetation affects soil temperature and permafrost through its role of shielding the ground surface and permafrost from solar heat. Much of this protection is provided by the insulating properties of the widespread moss and peat cover associated with northern soils (Brown, 1970). Removal or disturbance of the surface vegetation may cause degradation of the underlying permafrost. It has been suggested that the occurrence of permafrost is related to changes in the thermal conductivity of the surface organic materials throughout the year (Brown, 1966 a). During the summer the surface layers of peat become dry through evaporation. The thermal conductivity of the peat is low and warming of the underlying soil is impeded. The lower peat layers gradually thaw downward and become wet as the ice layers in the seasonally frozen soil melt. In autumn there tends to be more moisture in the surface layers of the peat because of a decreased evaporation rate. Consequently as the peat freezes later in the fall, its thermal conductivity is increased considerably. Peaty surface layers normally offer greater resistence to cooling of the underlying soil in winter than to its warming in summer. As a result, mean annual ground temperature under the peat layers will be lower than under adjacent areas without peat.

Soils in the bog veneer of Site 1 (Transect C, Sites C8 through C4 and C2, Figure 3) are characterized by surface peat accumulation and persistence of permafrost. The depth of annual thaw varies considerably as a result of alteration of thermal condition in the surface layers of organic matter by seasonal weather patterns (Figure 13). Increased thickness of active layer or complete disappearance of frost result if greater warming occurs in summer than cooling in winter.

Fire is a natural occurrence in the boreal forest that influences distribution of vegetation types and vegetation succession. An opportunity to monitor the impact of vegetation on soil temperature, water table and permafrost is provided in Transect H of Site 2 as it was burned about 15 years prior to initiation of the present study. In contrast to conditions in Site 1, the organic veneer in Site 2 is much less extensive and there is no permafrost. However, broken and disturbed horizons in the soil at H1 may be relict cryoturbation features

Table 3 Relation of weather characteristics to distribution of permafrost and thickness of active layer in Benchmark Site 1.

Weather Characteristics		Frost Characteristics					
		Site with Frost			Active Layer		
Freeze Season	Thaw Season	Date	No	%	In-crease	De-crease	No Change
1980-1981 Fall Average snow Winter Warmer, drier Spring Below average snow	1981 Warmer drier	81-9-17	34	68	-	-	-
1981-1982 Fall Average snow Winter Cooler, wetter Spring Average snow	1982 Average temperature, drier	82-9-14	31	62	21	10	6
1982-1983 Fall Early above average snow Winter Warmer, wetter Spring Late snow persistence	1983 Warmer, wetter	83-9-20	35	70	27	10	2
1983-1984 Fall Below average snow Winter Warmer, drier Spring Above average spring snow	1984 Average temperature, drier	84-9-16	23	46	29	5	-

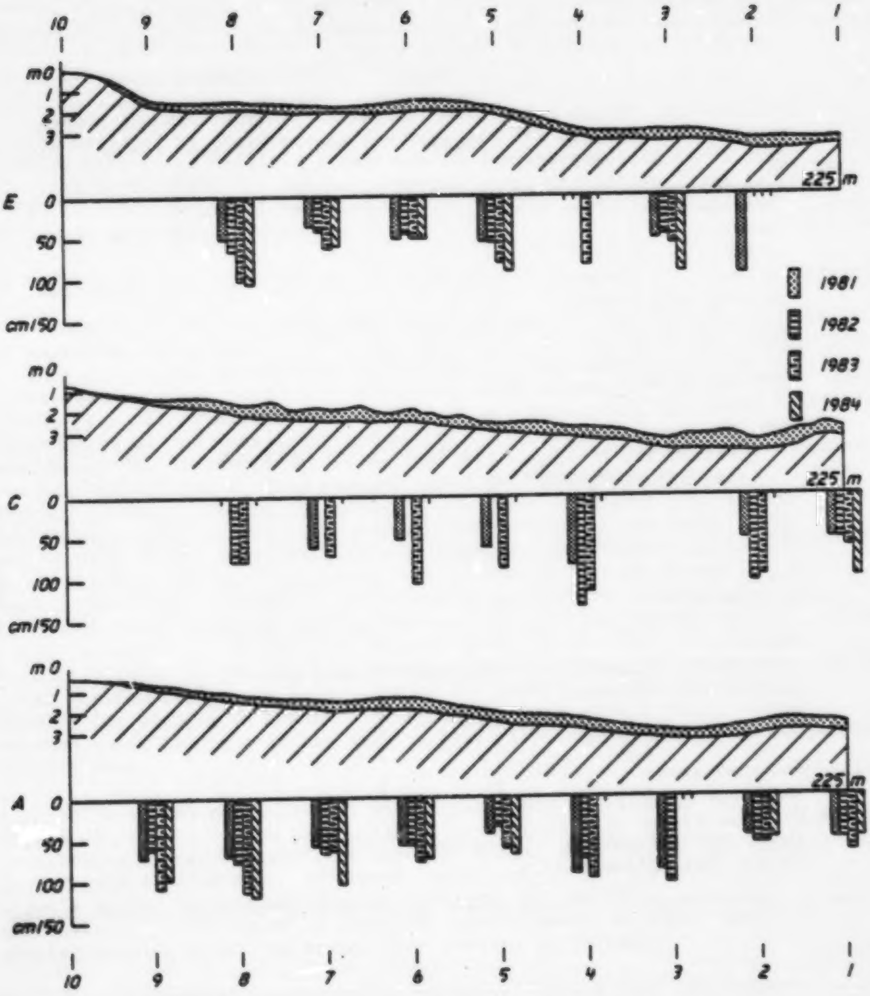


Figure 13. Fluctuation in Depth of Active Layer Transects A, C and E
Site 1, 1981-1984

associated with permafrost prior to the fire. Complete removal of shade and insulation provided by the vegetation cover and surface organic matter layers caused the soils to warm sufficiently that the permafrost melted. The pronounced micro hummocky surface patterns encountered on the upland positions of each Transect may result from cryoturbation associated either with permafrost or with seasonal frost.

Following the fire, renewed development of the organic veneer continues to alter the soil moisture regime, particularly on the lower slopes of very gently sloping landscapes. This process of peat accumulation known as paludification is encouraged by the cool, humid climate in the Thompson area. The organic veneer retains precipitation, reduces surface runoff and acts as an insulating blanket. Soil material underlying the peat layers becomes wetter and colder. Paludification of very gently sloping landscapes over time results in development of soil drainage, vegetation and eventually permafrost conditions similar to those observed in Site 1.

SUMMARY

Thin organic veneers characteristic of lower positions in very gently sloping landscapes in this area of Manitoba significantly alter both soil moisture regime and surface drainage. Soils underlying the veneer remain saturated for longer time periods than are soils without the veneer.

The peaty surface layers alter the soil thermal regime causing underlying mineral soils to be affected by greater cooling in winter than warming in summer. The colder soil temperatures associated with these soils appear to retard microbial activity, reduction processes and the development of soil colour and mottles presently used as criteria to describe saturated soil conditions.

As the organic veneers accumulate, the colder soil temperature results in average deeper frost penetration each year accompanied by increased insulation and the eventual development of permafrost. Very gently sloping topography, soil moisture content, dense vegetation cover and thickness of surface organic layers are the major factors affecting cold soil temperatures and the persistence of permafrost.

Permafrost is a major feature associated with central and northern areas of the boreal forest in Manitoba. Preliminary evaluation of data from the two study sites suggests that permafrost in the discontinuous permafrost zone exists in fragile equilibrium with its environment. Seasonal patterns of weather affect the soil moisture and thermal regime and alter the thickness of active layer.

Monitoring of the permafrost in undisturbed landscapes shows annual and seasonal variation in distribution of frost and thickness of seasonal thawing. Disturbance of the surface vegetation in these soils results in increase of soil temperature and thickness of active layer. Complete removal of the surface vegetation causes melting of the frozen subsoil and disappearance of the permafrost.

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TRANSIENT GROUNDWATER FLOW SURROUNDING A RECHARGE SLOUGH IN A TILL PLAIN

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INTRODUCTION

Sloughs in agricultural areas have often been the subject of controversy. They have been variously viewed as: wetlands providing wildlife habitat, an obstacle to mechanized agriculture, part of the water resources of the region, or storage for rainfall and snowmelt that prevents stream flooding. The groundwater flow system around the slough has important implications in all of these aspects.

This study reports on the transient flow system associated with a slough in a particular hydrologic setting. An attempt was made to determine the factors influencing the groundwater flow so that the results could be generalized to other hydrologic settings.

SITE DESCRIPTION

The site, consisting of a group of sloughs, is located just east of the town of Hamiota, Manitoba, in the south west quarter of 11-14-23W1. This 64-ha field contains over thirty sloughs, and is usually cropped to cereals or annual oilseeds. Other fields in the vicinity have similar numbers of sloughs.

The landscape is a till plain containing numerous closed depressions and having a hummocky appearance, although the local relief is only about 2 m. Many of the depressions contain temporary sloughs, which fill with water in the spring, become dry in the summer, and develop a lush vegetation cover. The area has little or no integrated surface drainage. Glacial meltwater channels are prominent features, but they are not part of any present drainage system. Similar landforms cover wide areas of Manitoba, Saskatchewan, and the adjacent U. S. states.

The stratigraphy (Figure 1) was determined by Lissey (1968). The till deposit, about 21 m thick at this location, is of mixed origin, containing clasts of various sizes in a clay loam textured matrix. Because of its high clay content and compact form, the hydraulic conductivity of the till is very low. The upper metre of till that is subject to pedogenic disturbance would be expected to have a higher conductivity. Below the till is the hard, gray, highly-jointed Odanah shale. The hydraulic conductivity of the shale is approximately three orders of magnitude greater than that of the till.

The site is part of a regional recharge area in the Oak River basin mapped by Lissey (1968), containing fast and slow recharge sloughs, where water infiltrates to recharge the shale aquifer. The water table is in the upper part of the till deposit. The hydraulic head in the shale is much lower than the water table, indicating downward flow in the till. Groundwater in the shale aquifer flows southward and discharges south of the town of Hamiota. Lissey indicates that recharge areas such as this cover 70% of the Oak River basin.

Al-Taweel (1983) made a detailed study of the soils of the site. He found striking variations in the type of soil profile that had developed in different topographic positions, and related these to variations in the long-term water regime. He also described a band of saline soil that partially encircles the principal slough and investigated secondary salt and carbonate deposits in these soils.

FIELD RESEARCH

The instrumentation for groundwater measurement were installed on two transects extending radially outward from the center of the principal slough. Water table observation wells varied from two to six metres in depth, depending on topographic position. Shallow piezometers were arranged in nests of two or three piezometers per nest, with tips at 1.5 m to 6 m depth. In addition, a portable tensiometer was used to obtain the potential beside each piezometer nest in the unsaturated zone, at 45 cm depth. Readings were taken every three to five weeks, with additional ones taken in the spring and early summer when conditions were changing rapidly. Levels of water in the sloughs and time of drying were also noted. Soil temperature was monitored, as well, using arrays of thermocouples between 2.5 cm and 1.5 m depth.

Over the four year observation period, the water levels in all of the wells and shallow piezometers rose and fell in an annual cycle (Figure 2). This cycle was apparent along the whole transect from the knoll to the depression, although the amplitude increased considerably in and near the depression. The phase and shape of the cycles also varied along the transect. In the depression, there was an abrupt rise in April, and a rapid decline in July or August. The rise and decline were more gradual and occurred somewhat later in the year, in the area between the knoll and depression. Under the knoll, there was a slow rise, beginning in June, to a maximum in October, and an equally slow decline until the following June.

Vertical gradients below the water table, as revealed by the shallow piezometers, were always rather small, and frequently non-existant. Gradients in the unsaturated zone generally corresponded in direction to those in the saturated zone, although the magnitude was often greater. Figure 3 is a typical equipotential diagram. In the area between the knoll and depression, upward gradients were associated with a falling water table, and downward gradients, with a rising water table, suggesting removal and addition of water at the surface. In the spring and early summer, when water was ponded in the depression, vertical gradients were insignificant. The decline of the water table in the depression, during July, August, and September, was accompanied by an upward gradient, presumably due to evapotranspiration. At the knoll position, the gradient was upward most of the time, regardless of the movement of the water table.

The annual cycle of the water table must be related with the rapid addition of water to the system that occurs in the spring, in particular, with the ponding of water in the depression (Figure 4). Field observations indicate that as soon as the frost thaws in the slough bottom to permit infiltration, the water table below the slough rises and coalesces with the ponded water. Some outward groundwater flow away from the slough is undoubtedly caused by this elevated water table. One explanation, later rejected, for the delay of the water table rise along the transect from the depression to the knoll involves a slow outward flow from the depression which reaches the location of the knoll after several months of travel.

The band of saline soil in the cultivated field around the slough indicates that there is a net upward flux of groundwater in this zone. Seasonal proximity of the water table to the surface could account for this. Well-developed and non-saline soils outside the saline ring indicate a net downward flux at these locations. Evidently, as the water table becomes deeper below the surface, exfiltration from the water table becomes insignificant in relation to infiltration from normal precipitation. There is also a band of poorly-developed but non-saline soil inside the saline ring. Here the seasonal water table is even higher, but the discharge is fresh water because of the very short flow path from the slough.

SIMULATION RESEARCH

Groundwater research in the field is restricted in its scope by the site conditions that prevail and, in particular, by the weather conditions that occur during the study period. Interpretation of the field data, according to the accumulated principles and theories of hydrogeology, is always required. Simulations complement field studies because they permit experimentation with a model of the field system where the various factors that affect groundwater flow can be varied independantly. Transient, saturated and unsaturated flow, as occurs at the Hamiota site, is described by a non-linear parabolic partial differential equation. A numeric simulation of this equation by the finite difference method over a two-dimensional cross-section requires the solution of a matrix of simultaneous non-linear equations at each time step. Brutsaert (1971) has developed an efficient computer method, using Newton linearization, to perform this simulation.

When given input consisting of the dimensions and physical properties of the system plus the initial groundwater conditions, the program displays the distribution of saturation and potential at various times during the simulation run. The flow system chosen for simulation at the site east of Hamiota was one half cycle of the topography along a cross-section from the knoll to the depression. A homogeneous isotropic medium with an impermeable lower boundary was specified, with a level water table about three metres below the bottom of the depression, and the soil above the water table in capillary equilibrium with the water table. These conditions approximate the system in the field just before the spring infiltration begins. The first runs were started with water ponded in the depression in order to observe the growth and dissipation of the groundwater mound. Later runs were started with the upper metre of soil along the whole transect at saturation in addition to the ponded water. This was an attempt to simulate the wet conditions that might occur in the spring due to thawing of frozen soil and infiltration of snowmelt. Finally, flux terms were introduced to simulate evapotranspiration at the soil surface along the transect.

A number of significant results were obtained from the simulation runs (Figure 5). Many of these are consequences of the very low hydraulic conductivity of the till, which severely restricts water movement. The growth of the groundwater mound by infiltration below the slough corresponded reasonably well with behavior observed in the field. The recession of the water level in the slough was mainly due to evaporation, rather than seepage. Similarly, once the slough had dried, the dissipation of the groundwater mound was primarily due to loss of water by evapotranspiration, although horizontal saturated flow was also a significant mechanism. Outward flow from the depression did cause a rise in the water table at the edge of the depression, but had no effect on the water table along the rest of the transect. It was only when initial surface saturation was introduced that a water table rise similar to that recorded in the field appeared in the simulation. A rise and fall was produced when both initial surface saturation and evapotranspiration were included in the model. Limitations in specifications of data precluded duplication of field observations in a quantitative manner but the results outlined here do help to identify factors that are important in the flow system.

DISCUSSION

The Groundwater Flow System

At the study site east of Hamiota, a local groundwater flow system is superimposed on the regional flow system. The driving force for the local system is seasonal ponding, saturation, or evapotranspiration at the surface. In general, the flow is nearly vertical in the unsaturated zone and nearly horizontal in the saturated zone. This is a consequence of the contrast in hydraulic conductivity between the unsaturated and saturated flow medium. Of course, there is not a sharp boundary between these two zones as there would be in the case of a stratigraphic change. Much of the flow is focused on the depression. That position has the widest range of water table level: from ponded water in the spring to several metres below the surface in the fall and winter.

The area of influence of the slough is restricted by the low hydraulic conductivity of the till. While water is ponded in the slough, there is some outward saturated flow and part of this is diverted upward by evapotranspiration. Later in the summer, when a depression of the water table has formed below the slough, a reversal of flow occurs so that groundwater moves toward the slough. At certain times of the year, the water table in the cultivated field near the slough is within a metre or two of the surface. Calculations indicate that even at these times, capillary rise will not supply a significant amount of water to the crop. However, crops with roots that penetrate to these depths can certainly withdraw the water. Outside the area of influence of the slough, episodes of infiltration and exfiltration act to raise or lower the water table.

Meyboom (1966) studied the groundwater flow system around a similar slough in the Allan Hills of Saskatchewan. The till deposit there is much thicker and the relief and regional slope are greater than at the Hamiota site. The till also has a higher hydraulic conductivity so that the area of influence of the slough was correspondingly larger. Meyboom discovered the alternation between outflow from the slough in the spring and early summer and a late summer reversal of flow back toward the slough. He attributed the flow reversal to movement of groundwater toward the water table depression created by the willow ring and the vegetation filling the slough.

The groundwater in the till is not particularly useful as a source of water. Shallow wells in the till have a very low yield unless they happen to intersect a lens of stratified material within the till. Water from the till does recharge the shale aquifer, but the flow across the 17 m of till must be very slow because of the low hydraulic conductivity. The recession of the ponded water in the spring and summer cannot be directly related to recharge of the deep aquifer. Most of this water is lost by direct evaporation or enters the local flow system and is lost by evapotranspiration. Meyboom reported that the slough in the Allan Hills alternately recharges and discharges the regional groundwater. The net effect of this type of a local flow system may be small and certainly is difficult to determine.

Factors Affecting Shallow Groundwater Flow

The local groundwater flow system around a slough is determined by the regional hydrologic setting, as modified by local additions and removals of water. When the regional flow system is weakly expressed, it can be dominated or reversed by the local flow system. At the Hamiota site, a sequence of local seasonal recharge and discharge zones have developed within a regional recharge area, as a response to the hummocky topography. Soil properties, particularly hydraulic conductivity, also have a great influence. Low conductivity materials, such as the till at the Hamiota site, allow large hydraulic gradients to develop, but flow rates will be low, and flow distances, short. The converse is true for materials of high conductivity. Another factor is the water supply to the slough. The persistence of ponded water in the slough depends on the balance of the water supply with losses by evaporation from the surface and inflows or outflows by seepage. In a study of ten sloughs in central North Dakota over a five-year period, Shjeflo (1968) determined that 48% of the water supply was from direct rainfall on the water surface, but that 31% was from snowmelt and 21% was from rainfall runoff in the surrounding watershed. The latter two sources can be quite variable. Refering to the North Dakota study, Eisenlohr (1972) concluded that the conditions that favoured a large contribution from snowmelt were a snow cover that remained until spring and then melted rapidly while the ground was still frozen. Likewise, rainfall that occured after the soil surface had been saturated by a previous rain favoured runoff into the depression.

In the area surrounding the slough, water is added to the flow system by infiltration and removed by exfiltration. These exchanges, together with deeper flows, determine the transient position of the water table. Infiltration can result from snowmelt or thawing of frost in the spring, or from rainfall in the summer and fall. At the Hamiota site, infiltration in the spring appears to be responsible for the annual rise of the water table along the transect from the knoll to the depression. Similarly, Shjeflo (1968) reported that in May, the water table at the edge of a slough rose to 60-90 cm above the water level in the slough. He attributed this to thawing of frost in the soil. Exfiltration is primarily due to consumption of water by plants, and it becomes dominant in the summer when temperatures are highest and the plants are actively growing. In the winter, water can also move upward from the water table to accumulate as frost near the soil surface. The annual decline of the water table at the Hamiota site is likely a result of exfiltration by both of these mechanisms.

Application of Groundwater Data

A good deal of information about local and regional groundwater flow systems can be obtained without detailed hydrogeological study. Lissey (1968) mapped regional recharge and discharge areas by observing natural vegetation communities around undisturbed sloughs in the early fall. The rate of water level recession over the summer months and the salinity of the water can similarly be used to indicate slough hydrology. Soil profile types are also good indicators. A profile that has a well-developed "B" horizon and a deep solum that is free of carbonates suggests a long-term net downward flux of water. Conversely, a net upward flux is suggested by a poorly developed profile with an accumulation of carbonates and salts near the surface. Hydraulic conductivity of the materials is a critical factor, but this can often be estimated from descriptions of the surficial deposits or soil parent materials.

Sloughs are of little benefit to agriculture and do occupy land that could otherwise be used for crop production. At the Hamiota site, crop growth in a narrow band at the edge of the slough is sometimes enhanced by the shallow water table there, but growth is often depressed by the salinity that has developed around the slough. Sloughs that regularly go dry in the summer are not even useful as waterfowl habitat or as a source of water for agriculture. Knowledge of the groundwater flow system associated with a slough provides an insight into the changes that might occur when the slough is drained.

Consequences of slough drainage include a reduction in groundwater recharge, a loss of stored water, and an increase in water entering the surface drainage system. Recharge is not necessarily beneficial, particularly if it results in wet and saline conditions in an adjacent discharge area. Drainage of small and temporary sloughs into one larger slough is an alternative to complete removal of the water that offers some advantages. Guidelines for slough drainage should be formulated to weigh the benefits and consequences of slough drainage, but must also consider the hydrogeology of the slough and its environment.

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LIST OF FIGURES

Figure 1: Stratigraphy at the site east of Hamiota.

Figure 2: Hydrographs of shallow piezometers at four topographic positions:
(a) Depression. (b) Lower slope. (c) Middle slope. (d) Crest.

Figure 3: Hydraulic head distribution at the site east of Hamiota.

Figure 4: Seasonal fluctuation of the water table.

Figure 5: Saturation and potential output from simulation runs:
(a,b) Infiltration of water ponded in the depression. (c,d) Persistence of the groundwater mound below the depression. (e,f) Progressive water table rise due to initial surface saturation. (g,h) Falling water table due to evapotranspiration at the surface.

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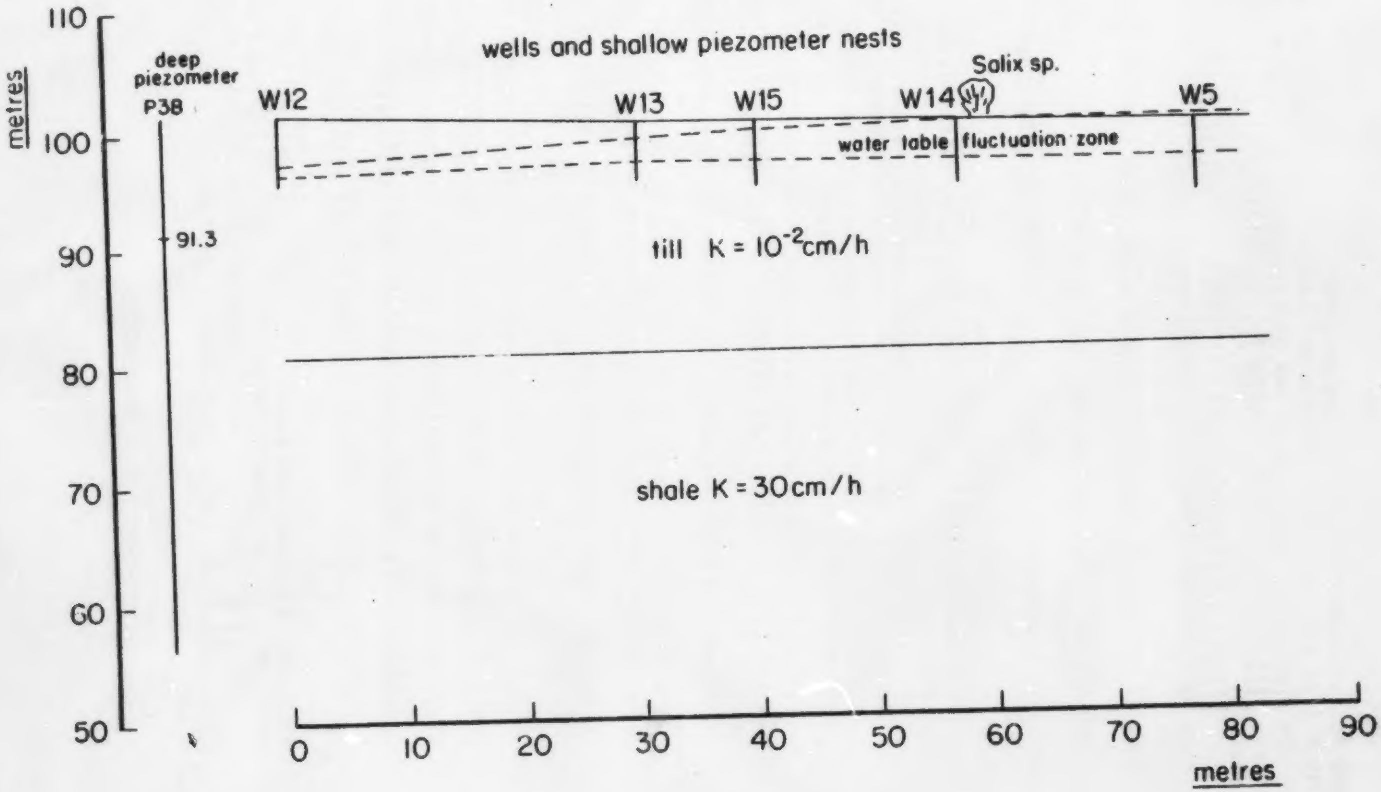
Stratigraphy - East of Hamiota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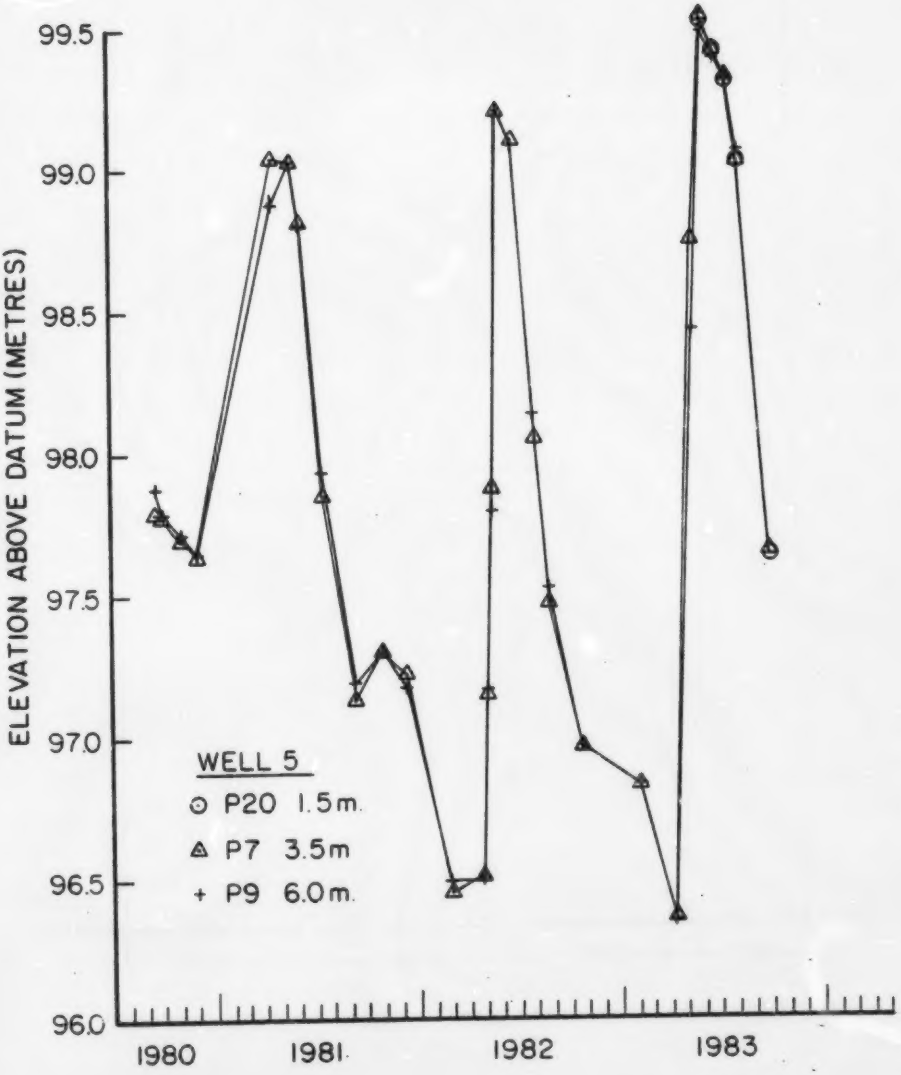
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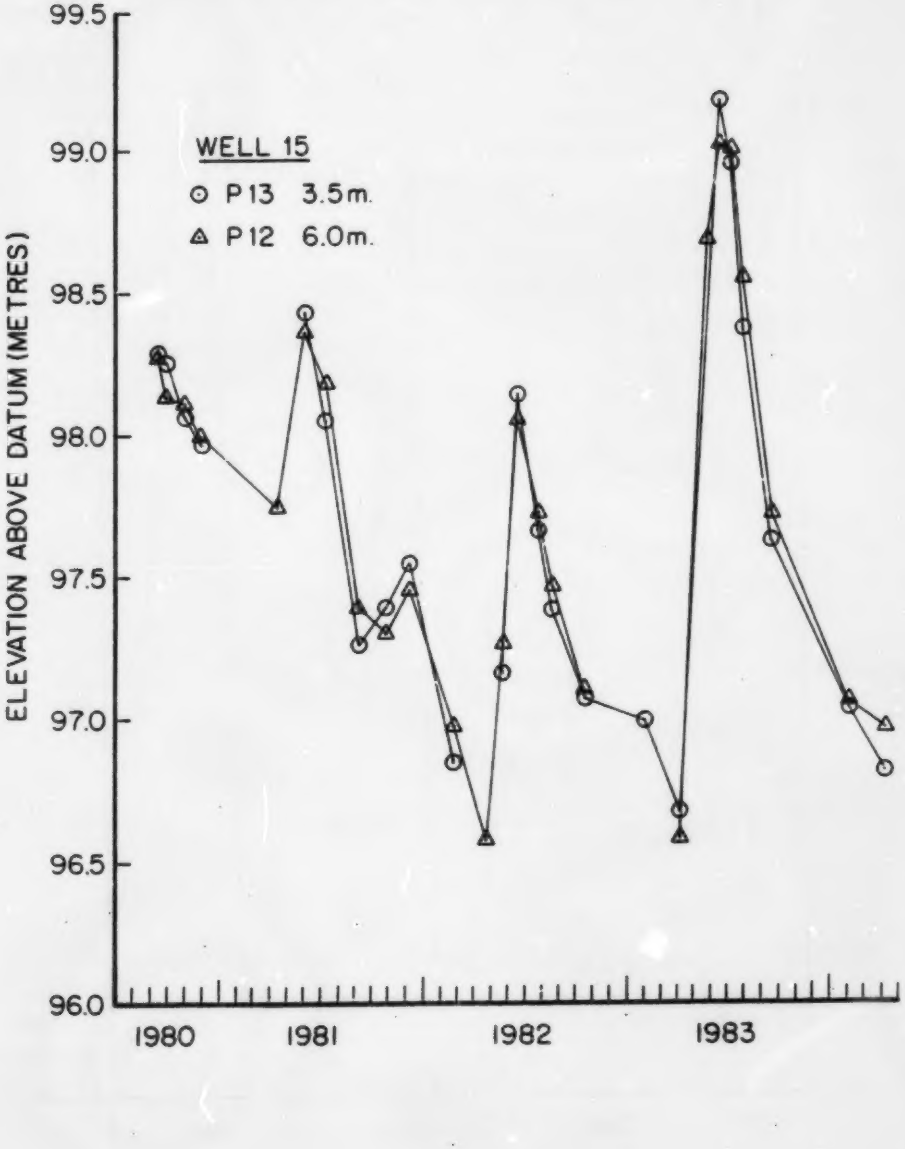
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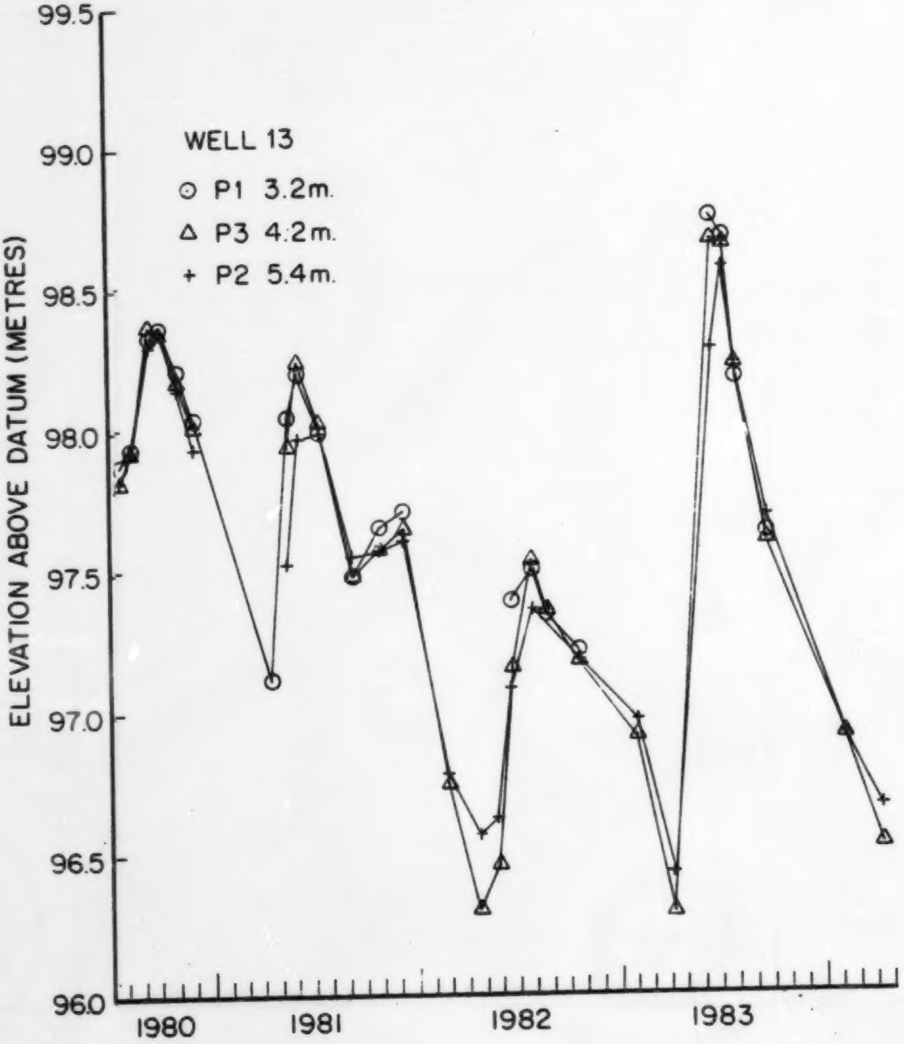
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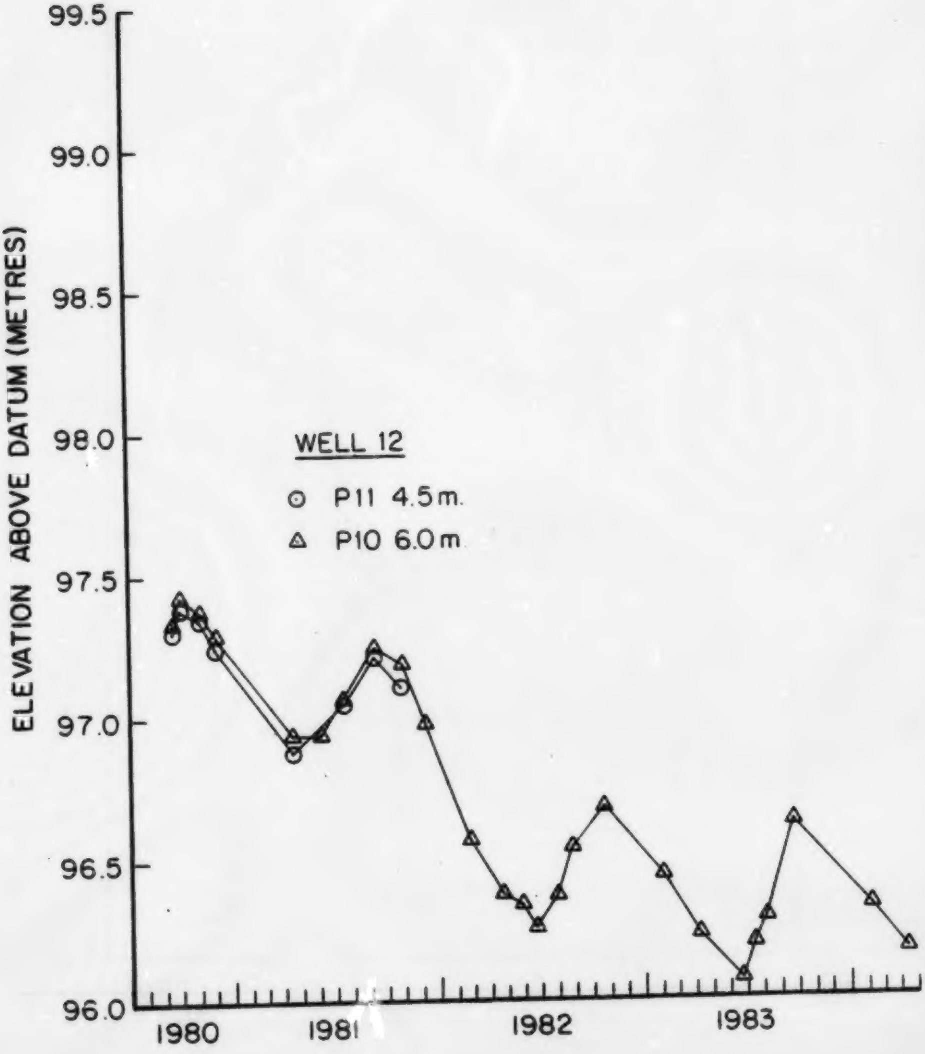
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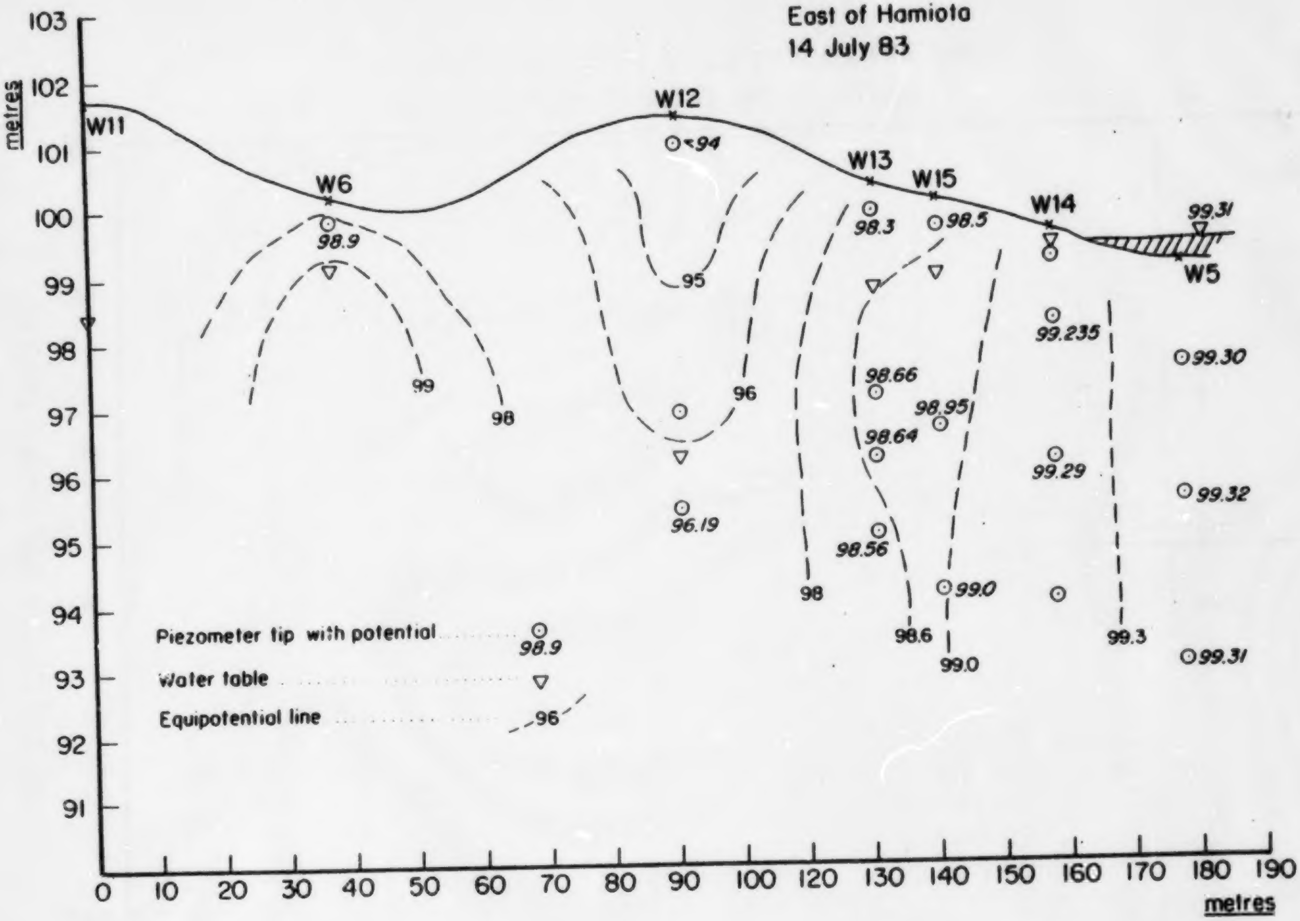

East of Hamiota
14 July 83

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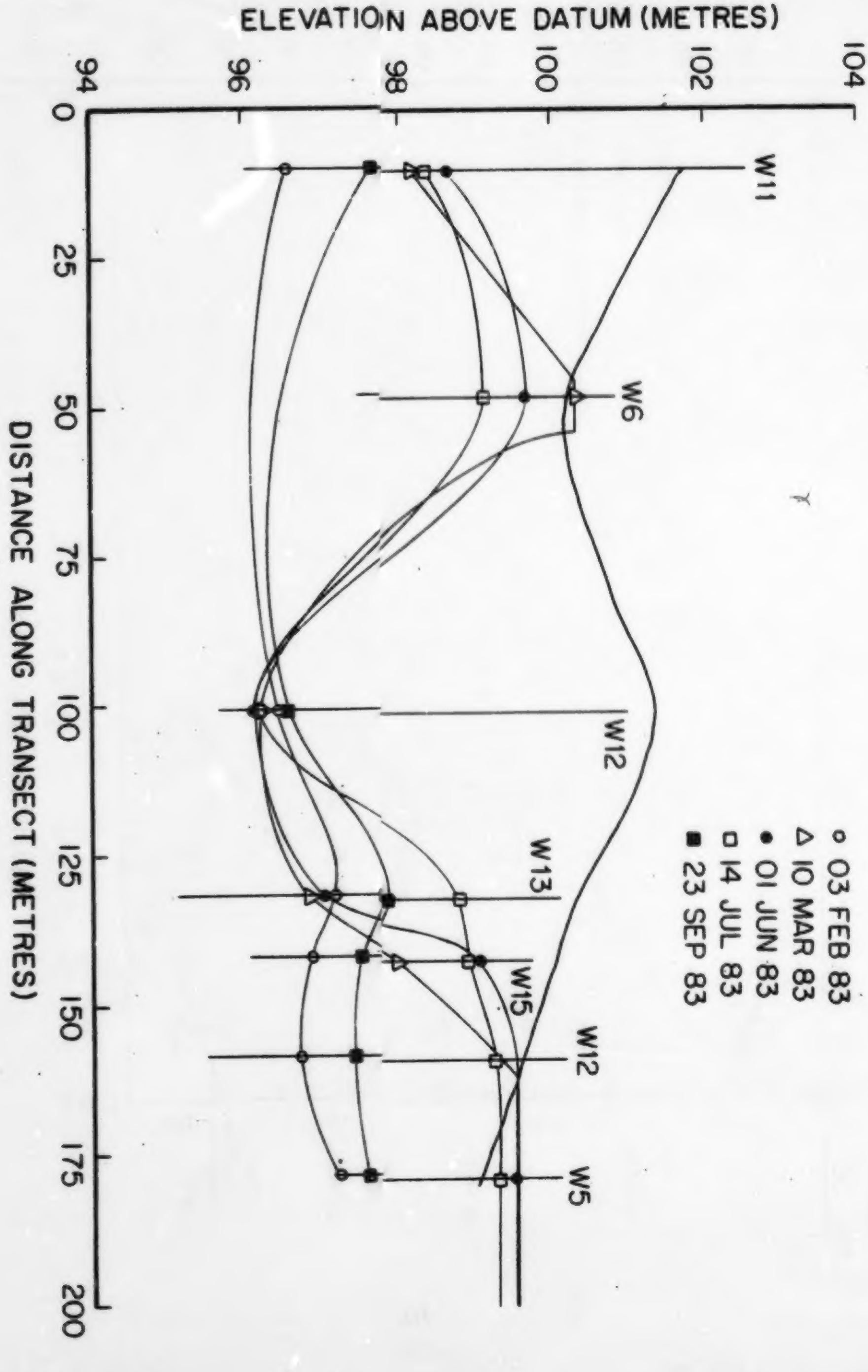
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□ 14 JUL 83
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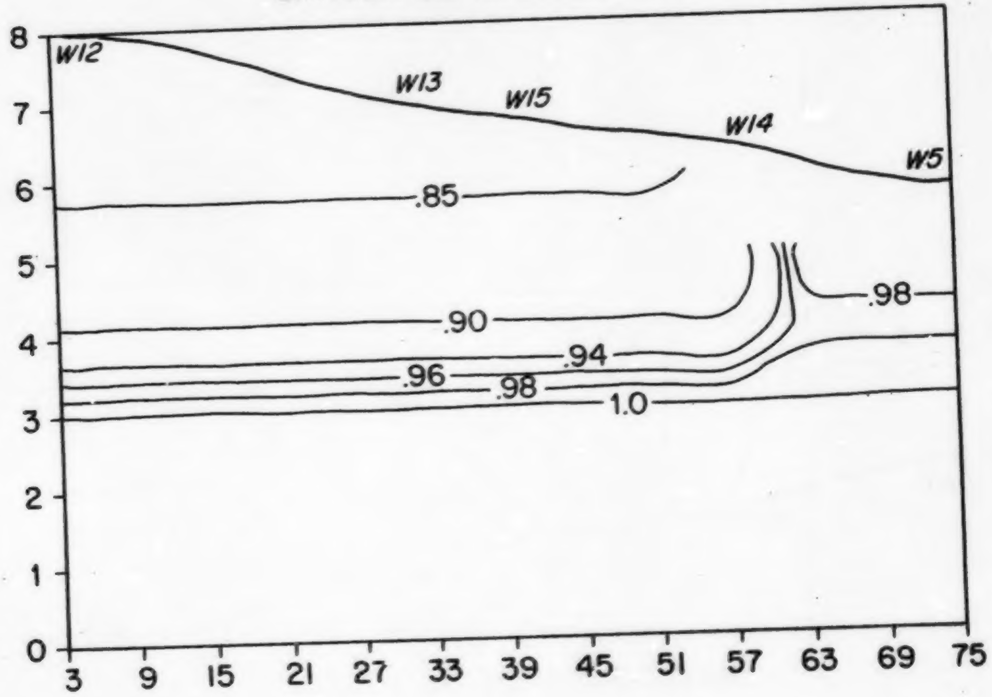
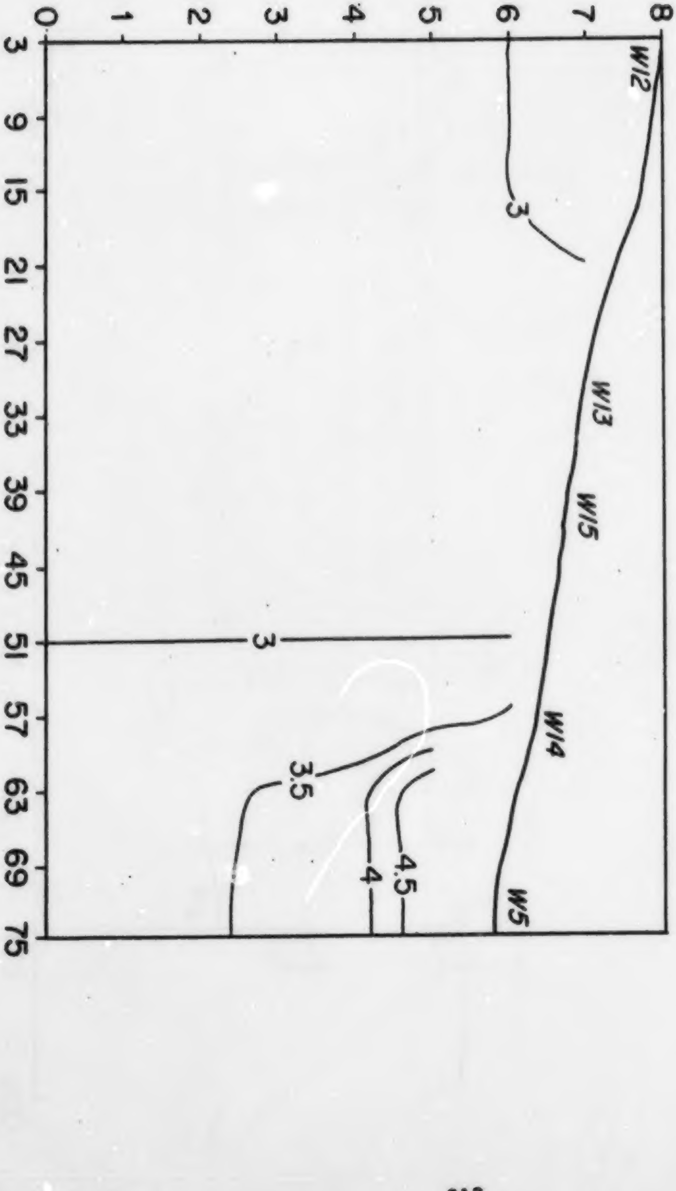
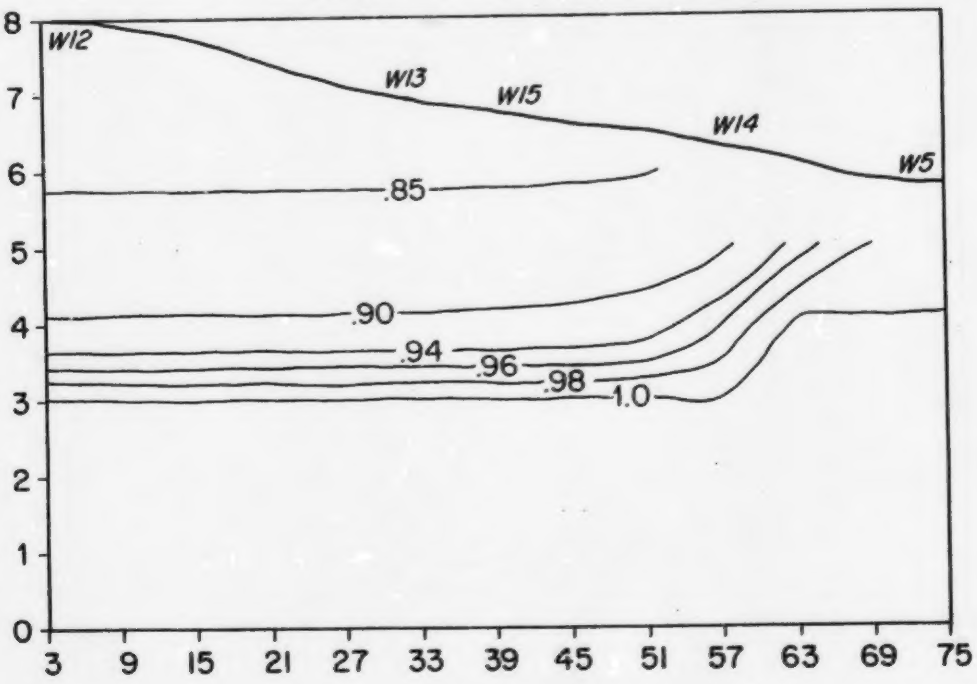
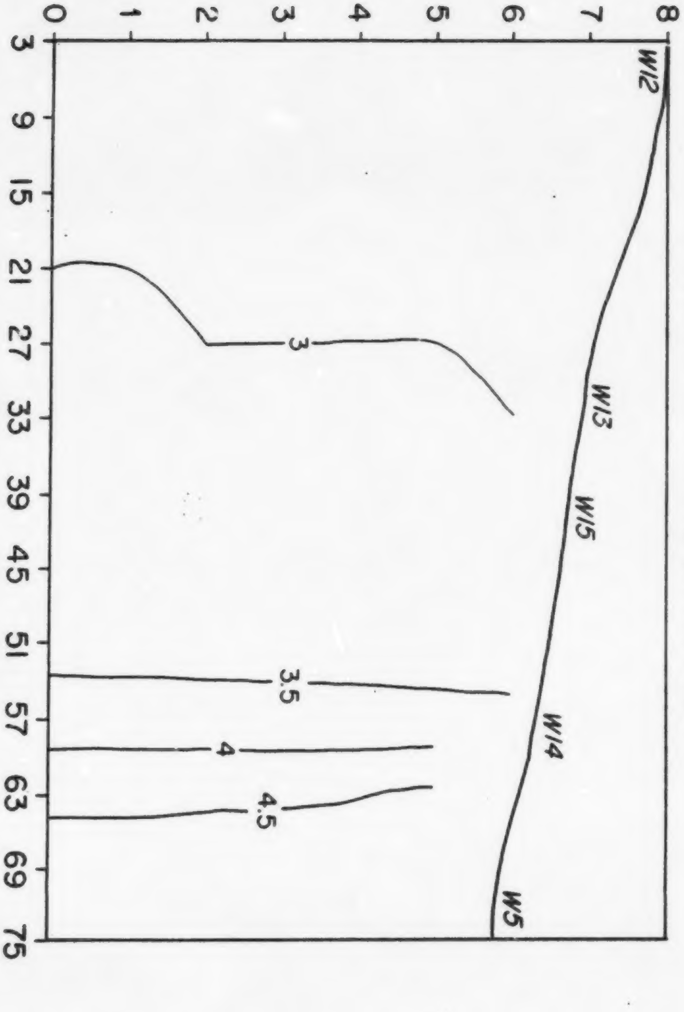

SATURATION AT 400.0 HOURS

POTENTIAL AT 400.0 HOURS

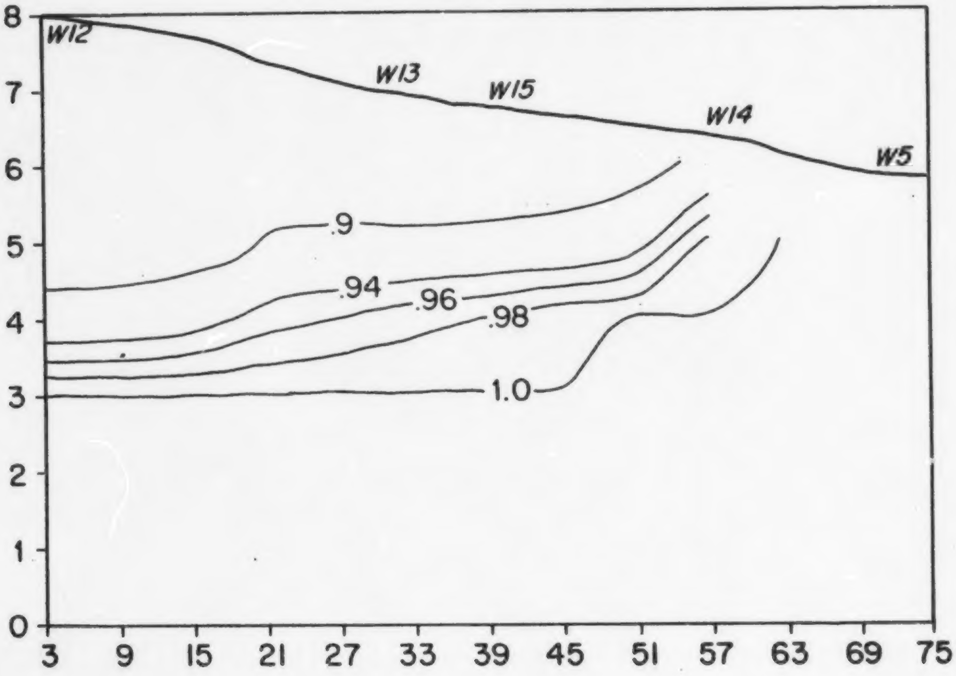




SATURATION AT 4000.0 HOURS

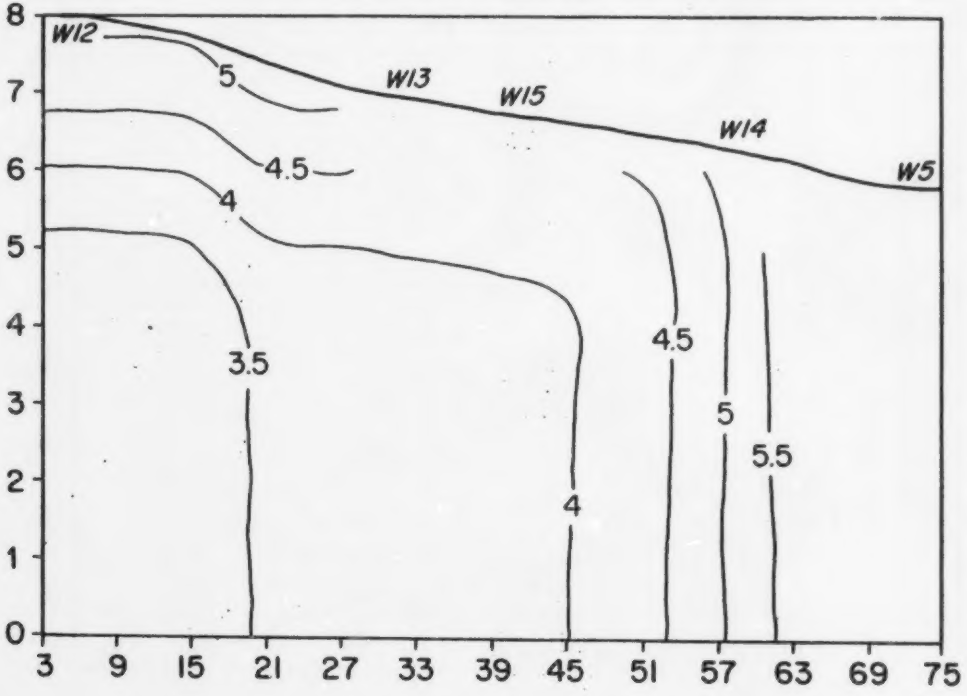


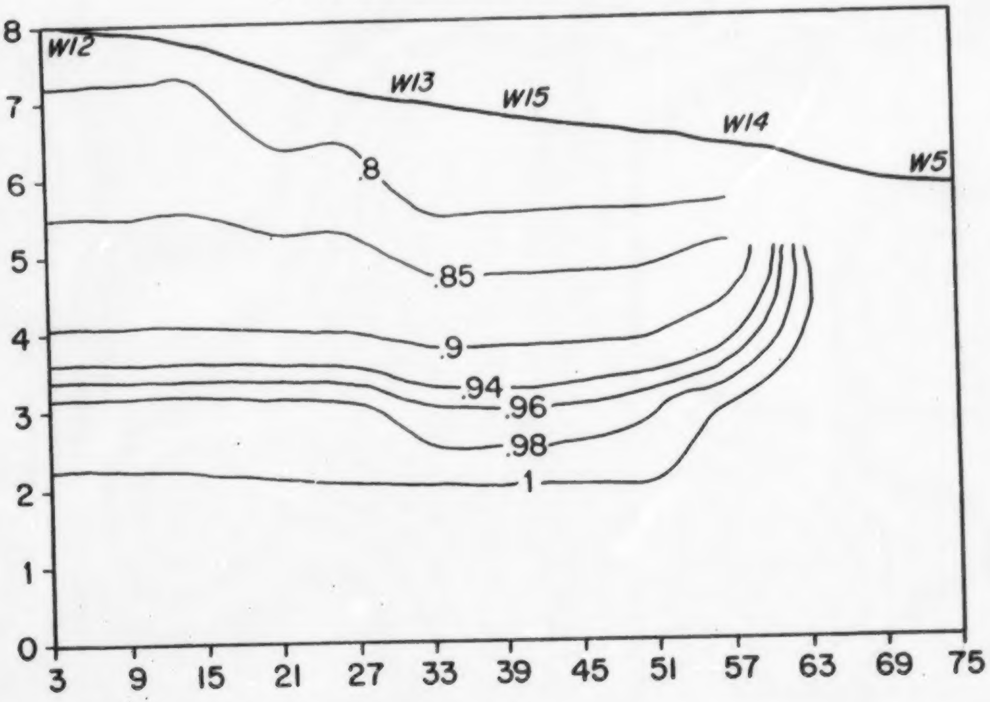
POTENTIAL AT 4000.0 HOURS



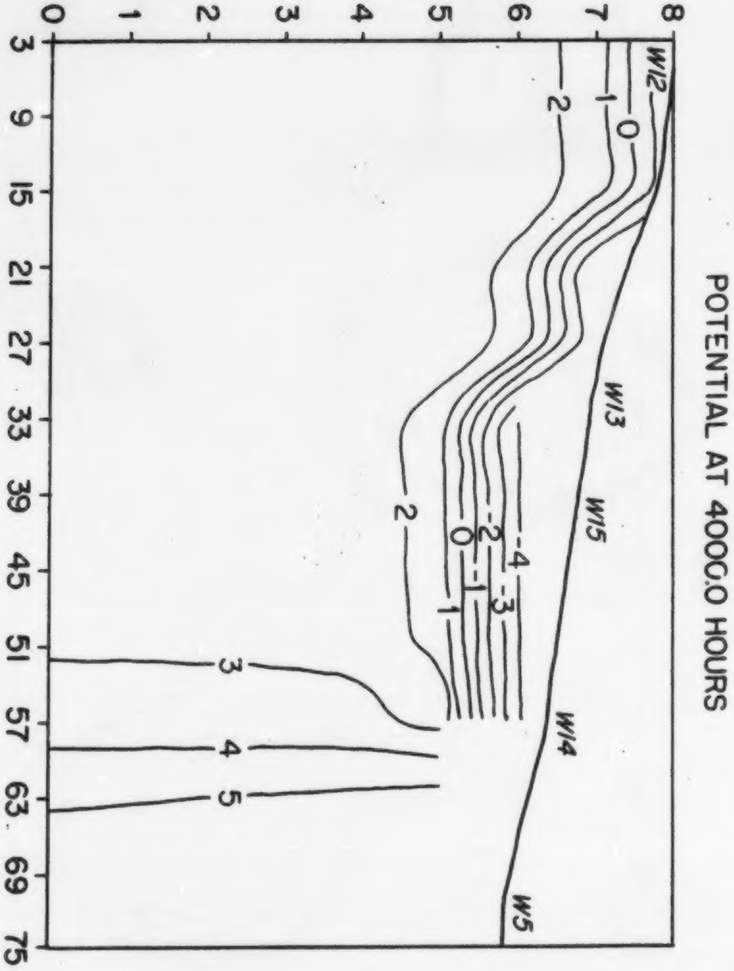
SATURATION AT 4000.0 HOURS

POTENTIAL AT 4000.0 HOURS





SATURATION AT 4000.0 HOURS



POTENTIAL AT 4000.0 HOURS

CANADA-MANITOBA SOIL SURVEY STATUS REPORT FOR 1984-85

R.E. Smith
Canada-Manitoba Soil Survey

The joint federal-provincial Canada-Manitoba Soil Survey, for the period of review of April 1, 1984 to March 31, 1985, continued to pursue a balanced program of inventory both in Manitoba and the Northwest Territories, research and development activities to improve soil survey procedures, and improvement of soil resource interpretations and evaluations for various uses. See Figures 1 & 2 and Tables 1, 2 & 3 for a more complete summary of coverage.

INVENTORY - MANITOBA

a) Detailed Resurvey 1984

The progress of this continuing project in southern Manitoba keys on areas where more intensive arable agriculture is being practised, where soil erosion due to wind and water is becoming acute, where irrigation development potential is high, where concern for the safe disposal of solid and liquid waste is high and in pressure areas where urban-rural land use conflicts are required to be resolved. The areas covered in the 1984 field program include:

Table 1. Detailed Resurvey Coverage 1984

Project		Coverage in Hectares	
		1:20,000	1:50,000
Manitoba Agriculture and Canada Agriculture			
D60	R.M.'s Dufferin & Grey*	59,616	
R29	R.M. Lorne*	5,184	59,616
Manitoba Municipal Affairs			
D63	Shellmouth Reservoir	3,626	
D64	S. Assiniboine R. in R.M. S.Cypress	4,144	
D65	Villages of Hamiota, Strathclair, Rapid City, Springstein & St. Eustache	4,403	
D66	R.M. of Springfield	12,950	
R30	R.M. of Swan River*		18,648
Department of Environment			
	Spruce Point Drainway	1,295	
	TOTAL	91,218	78,264
	GRAND TOTAL	169,482	

* Continuing Project

Publications

Soil reports for the Pasquia (D63) and Swan River Townsite (D37) have been published. The compilation and preparation for printing has been completed for 7 additional soil reports for Rat River (D39), St. Anne-La Broquerie (D49), Westbourne (D51), for areas surrounding the towns of Emerson, Letellier, St. Jean, Rosenort, Altona and Gretna (D53), Russel-Binscarth (D54), and Ste. Rose Du Lac (D55). These maps and reports provide rural planners, farmers, PFRA irrigation development planners, soil conservationists and parks planners with the type of base line information necessary for the planning and development of resources in Manitoba. They should be available for general distribution sometime during 1985.

b) Reconnaissance and Biophysical Surveys

Progress on the publication of the 1:125,000 scale survey coverage of areas bordering on the developed agricultural region of the province, within the Canada Land Inventory project, continues with the release of the Waterhen project (R17) for general distribution sometime in mid-1985 (Figure 1). Correlation, field sampling for enhanced soil characterization studies are being planned for the Swan Lake project (R18) in 1985.

In addition, a 1:125,000 scale survey of the Duck Mountain Forest Reserve, an area of approximately 55,426 ha, will be initiated in 1985. Compilation of maps and reports for the Grand Rapids (R20), Pointe du Bois (R23) projects will continue in 1985 as will the enhancement of the Cormorant Lake project (R21). The Biophysical survey project of the Island Lake area (B10) remains to be completed and no action is planned for 1985 due to other priorities.

c) Generalized Soil Map of Manitoba 1:1 M Scale

The compilation of the 1:1 M scale generalized soil map of Manitoba has been completed and digitized. An extended legend which will permit the development and production of a number of derived or thematic maps through CanSIS is currently being prepared. Among the more interesting of these derived maps to be produced and ready for publication in early 1986 are:

- A soil landscape map identifying physical and engineering properties
- A Soil Salinity map indicating degree and extent of the problem in the province
- A Wind Erosion Risk Map
- A Water Erosion Risk Map
- An Acid Sensitivity Map

INVENTORY - NORTHWEST TERRITORIES

The systematic exploratory inventory of areas in the N.W.T. continued in 1982 and 1984. The objective of this project is to provide land resource data for broad regional land-use planning and for updating the territories section of the Soil Map of Canada(1).

Personnel involved included H. Veldhuis of the Winnipeg Survey Unit, assisted in 1982 by K. Webb of the Nova Scotia Survey Unit and in 1984 by E. Woodrow of the Newfoundland Survey Unit.

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(1) Smith, R.E. 1980. Canada-Manitoba Soil Survey 1980 Progress Report in: Proc. 24th Ann. Man. Soil Sci. Meet., p. 1-11, Dec. 3 & 4, 1980.

In 1982, an area of approximately 400 000 km^2 was surveyed in the Great Bear River (NQ-9/10/11/12), Redstone River (NP-9/10) and Slave River (NP 11/12) 1:1 000 000 scale NTS map sheet areas(2). This area includes most of the territory between latitudes 62° N and 68° N and between longitudes 112° W and 128° W.

In 1984, the survey was continued in the Southern Keewatin area. Approximately 300 000 km^2 was surveyed in the Thelan River (NQ-12/13/14), Quoich River (NQ-15/16/17), Maguse River (NP-15/16) and Dubawnt River (NP-13/14) 1 000 000 scale NTS map sheet areas. The surveyed area extends from latitude 60° N to 65° N and from the Hudson Bay coast to latitude 104° W.

In addition, H. Veldhuis was involved in soil-landscape data compilation in the Queen Maude Gulf Project area, including the southern half of Victoria Island, King William Island, southern part of Boothia and parts of North Central Keewatin. This survey at the request of and in cooperation with the Lands Directorate of the Canada Department of the Environment, furnished data required for the Land Use Information Map Series of this area, published by the Lands Directorate.

In 1984, research was carried out in the Mackenzie Delta in cooperation with C. Tarnocai of the Land Resource Research Institute in Ottawa. The objective was to enhance data previously collected(3) and to investigate a number of areas not previously studied.

Table 3. N.W.T. Projects: Reports, Maps and Available Data

1. Tarnocai, C. 1973. Soils of the Mackenzie River Area. Environmental Social Program, Northern Pipelines, Rep. No. 73-26, 136 pp. Information Canada Cat. No. R72-9673, QS-1528-000-EE-A1.

   Zoltai, S.C. and C. Tarnocai. 1974. Soils and Vegetation of Hummocky Terrain. Environmental Social Program, Northern Pipelines. Rep. No. 74-5, 86 pp. Information Canada Cat. No. R72-13374, QS-1552-000-EE-A1.

2. Tarnocai, C., A.N. Boydell, J.A. Netterville and K.A. Drabinsky. 1976. Biophysical Land Classification Maps of Boothia Peninsula and Northeast Keewatin, N.W.T. Geol. Surv. of Canada, Open File #390, Ottawa.

3. Tarnocai, C. Data and preliminary maps for Prince of Wales and Somerset Islands, LRRI, Ottawa.

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(2) Veldhuis, H. 1983. Great Bear-Slave Rivers Survey Project, N.W.T. in: Proc. 26th Ann. Man. Soil Sci. Meet., p. 13-16, Jan. 10 & 11, 1983.

(3) Veldhuis, H. 1980. Soil and Vegetation Sequences in the Mackenzie Delta in: Proc. 24th Ann. Man. Soil Sci. Meet., p. 12-21, Dec. 3 & 4, 1980.

Table 3 (cont'd)

4. Tarnocai, C. Data and preliminary maps for Bathurst and Cornwallis Islands. LRRI, Ottawa.

5. Tarnocai, C. 1977. Soils of north-central Keewatin. Geol. Surv. Can. Pap. 77-1A, pp. 61-64.

6. Bradley, S.W., J.S. Rowe and C. Tarnocai. 1982. An Ecological Land Survey of the Lockhart River Map Area, Northwest Territories. Ecological Land Classification Series No. 16, Lands Directorate, Environment Canada, Ottawa.

7. Tarnocai, C. and Veldhuis, H. Soils of the Firth-Horton Rivers Area, N.W.T. LRRI, Ottawa. Maps and data. Report to be published in 1986.

8. Veldhuis, H. and K. Webb. Soils of the Great Bear-Slave Rivers Area, N.W.T. Preliminary maps and data, Winnipeg.

9. Veldhuis, H. and E. Woodrow. Soils of the Southern Keewatin Area, N.W.T. Preliminary maps and data, Winnipeg.

CANSIS

Development of the Manitoba CanSIS Node, one of a number of nationally coordinated series of provincial soil resource data banks, has been significant in 1984-85. Leading the list of developments has been acquisition of a number of pieces of electronic hardware including a new IBM-PC based stand-alone digitizer system. This new, in-house facility, supplied by LRRI, CDA, including a Calcomp plotter should provide a significant improvement in reliability and digitizing capability.

Enhancement and upgrading of soil resource information in the numerous national and tailor-made provincial files that comprise the Manitoba node continued. These files can be grouped into four main types: Cartographic Files, National CanSIS Files, Tailor-Made Manitoba Soil Survey Files, Other Provincial Files.

Cartographic Files

CanSIS production of reconnaissance (SIL3) information now covers approximately 8.5 M ha or 45 percent of present coverage for the province. Available digital information of detailed and semi-detailed resurvey projects is approximately 1.3 M ha or about 79 percent of the areas covered.

National CanSIS Files

These files, developed to meet the national objective of uniform soil characterization and evaluation, include:

a) The Detailed Soil Site (CanSIS "Soil Data") File - This file provides all available basic morphological, chemical, physical and environmental site information currently employed for soil characterization, evaluation and research. To date, approximately 1600 soil profile descriptions have been input and installed onto the University of Manitoba computer mainframe system. This allows for in-house manipulation of this data for such uses as the development of a standardized soil properties file, land evaluation modelling research and development, soil classification, correlation, other research. Data in the file is reasonably complete for only 40 percent of identified soil series mapped in the province. A systematic sampling of missing soil types mapped prior to 1959 is presently underway.

b) National Soil Names File - provides a comprehensive listing of all soil series or defined soil mapping units employed in soil survey in Canada, of valuable assistance in controlling consistency and quality of soil surveys.

c) The Soil Performance and Management File - This file serves as a national archive of documented soil fertility and land management research conducted since 1955 in Manitoba, including the Crop Variety Trials conducted by the Plant Science Department of the University of Manitoba. These data provide useful information to assess the impact of soil, climate and land management effects on crop production.

Manitoba Soil Data Files

These files have been created to accommodate and enhance soil survey operations covering such needs as:

a) The Daily Field Record - used to capture in digital format, relevant ground truth data collected at each observation site during the course of field mapping. Approximately 40,000 records have been completed between 1977 and 1984. This field record has been modified extensively over the past year to make it compatible with the Detailed Soil Site File and to be more useful in developing soil series descriptions and interpretations for various uses.

b) Manitoba Soil Names File - This file, compatible with the National Soil Names File, contains more information and is designed to help develop soil map legends and for soil type correlation in the province.

c) Soil Series Interpretations File - This file stores and outputs in standardized format, 17 different soils interpretations ranging from agricultural to engineering to recreational applications.

d) Monitoring Files - are presently being designed and developed to accommodate long term monitoring of such characteristics of soil as temperature, seasonal water table fluctuation at approximately 175 sites through southern and central Manitoba. The file is being developed to handle the monitoring of other soil properties such as salinity.

e) The Deep Drill Log File - another developing file to capture soil parent material properties data to depths of about 5 meters. These additional data are required for irrigation and engineering properties evaluations of special projects, e.g. solid and liquid waste disposal sites.

f) The Quarter Section Soil Series Identification File - to capture sufficient soil type and phase information by quarter section. Data is available for virtually all of the agricultural sector of the province and is presently used by the Provincial Soil Test Laboratory to enhance fertilizer recommendations and by Manitoba Agriculture, Crown Lands Branch to identify agricultural capacity classes. Other applications of this file will grow as more data is assembled.

g) Soil Survey Projects Index - to provide an up-to-date listing of soil survey projects, past and present, undertaken in the province (see Table 2).

h) Text Edit (MANTES) File - a University of Manitoba mainframe computer system providing low cost, in-house, automated text editing services that also includes a computerized type-setting capability. The Pas Soil Survey Report No. 22 is the first major use of this integrated text-edit system.

Other Tailor-Made Resource Files

A growing number of related soil, climate, land management and crop productivity files are also becoming increasingly important for land evaluation and soil resource use planning and management. These include data from the established Provincial Soil Testing File, Manitoba Crop Insurance File, Canada Environment Atmospheric Environmental Service Weather Data Base, the Manitoba Agriculture Crown Lands Br., Land Capability File (quarter section file), the University of Manitoba, Department of Soil Science Weather Data Base, the University of Manitoba Land Productivity Index File (PIXMOD). Interfacing with these data bases is currently being investigated to determine their role in the development of a Standardized Soil Properties Data Base for land evaluation modelling research.

Current Electronic Data Management Development Activities

1. Considerable effort is currently being expended to develop the Standardized Soil Properties File mentioned above. It is intended, as the name implies, to act as a central repository of information for all identified soil series in the province. It is proposed that it be established on a Soil Series basis with a large number of specific columns used to record processed data, including in many cases, generalized extrapolation of data from many different, non-specific data sources. It will function, in a sense, as a very large extended legend of soil properties for interpretations and land evaluation.

2. A Generalized Soil Description File is also being developed as a type of word processor file for report writing in order to streamline production of informal user oriented, survey reports.

3. Concurrent with improvements being made to the Daily Field Record is the development of a Lab Data Management System to operational capability by mid-1985. It is structured to keep track of various analytical routines completed and those required to be completed, to develop work sheets for each type of analysis needed, to provide a raw data capture and processing capability, to provide calculated values in an on-line disk file, generate error reports and print

processed data out in tabular format to be transferred to the Daily Data Accumulation File for loading to RAPID.

4. The recent development of reasonably priced office and field portable, hand-held, micro-computers has resulted in a major advance in data processing capabilities. An extended evaluation of these portable field and office micro-computer application to soil survey operations is currently underway in B.C., Alberta, Manitoba, and Quebec. Considerable savings can be achieved by streamlining the inputting of soil information through the use of suitable field dataloggers. Currently available hand-held, micro-computers, such as the Radio Shack 100, has significant limitations, in terms of its physical design in that it is more suited to an office environment rather than to field conditions where moisture and dust are serious problems. Memory capacity of such computers is also too limiting to handle all of the measurements taken during one day's field operations. Linear sequential programming for inputting data fields or the order in which they are to be done, is critical and can create serious inputting errors if menus are not rigidly followed. While available hand-held computers for use in the field are still not very good, progress in both hardware and software development is phenomenal with trends clearly towards less expensive models with larger memory capacity and well integrated software packages.

RESEARCH AND DEVELOPMENT ACTIVITIES

Perhaps the most significant developments over the course of the current review period in terms of research and development activities has been:

a) the increased attention being paid to developing guides and standards for the evaluation of soil deterioration in terms of extent, degree of severity and rate of change as to spread of soil salinity, water and wind erosion, acidification and organic matter losses due to cultivation. Prairie region survey groups are, in cooperation with the Soil and Water Conservation Section of PFRA, currently in the process of evolving such standards and guides under the leadership of R. Eilers (salinity), D. Cootes of LRRI, Ottawa (wind and water erosion) and G. Padbury (organic loss and its impact on crop productivity). These various groups are committed to producing, by 1986, a series of 1:1 M scale maps depicting the extent, degree of severity and risk of increased deterioration due to salinity, erosion, organic loss and acidification in the prairie region. These series of provincial maps would, it is hoped, provide a uniform and reliable assessment of land degradation in the prairies.

b) The second most significant achievement over the year has been the development to operational status of the Manitoba Land Productivity Index Model (PIXMOD) by C. Onofrei of the Soil Science Dept., in cooperation with Soil Survey. Validation and testing results have been very good. Current activities now focus on the development of suitable data bases, in terms of soils, weather variables and land management information, particularly seeding dates, status of available NO_3-N in soils as affected by current fertilizer practice before the model can be successfully applied on a province-wide basis.

c) Significant improvement in the standards and guides employed in the evaluation of soil suitability for irrigation development in the prairie region has been made under R. Eilers' leadership. His working group has now available, an integrated 4 class x 4 class soil and landscape, workable land suitability classification system that can be applied currently. It awaits final approval by the cooperating provinces and PFRA.

Table 2. SUMMARY OF SOIL SURVEY COVERAGE FOR MANITOBA JANUARY, 1985

Map Project Designation	Name (Soil Report No.)	Report Status[1]	Area in Hectares	Map Unit Description[2]	Survey Intensity Level[3]	Map Scale	Map Base[4]	Land Evaluation & Interpretations[5]
Detailed Studies and Surveys								
D1	Pasquia (No. 11)	Pub. 1960	57 200	a,b,d	3	1:63,360	Color	A
D2	Glenlea Research Station	Int. 1963	541	a,b	1	1:7,920	Photo	A
D3	Morden Experimental Farm	Int. 1961	256	a,b	1	1:12,000	Photo	A
D4	Onanole	Int. 1968	768	a,b	1	1:7,920	Photo	U
D5	York Factory Area	Int. 1969	768	a	3	1:63,360	B&W	
D6	McCreary Tile Drain Project	Int. 1971	64	a,b	1	1:5,000	B&W	A
D7	Brandon Experimental Farm	Int. 1985	768	a,b	1	1:7,920	Photo	A
D8	Portage Potato Farm	Int. 1972	480	a,b	1	1:4,800	Photo	A
D9	Portage la Prairie (No. 17)	Pub. 1972	113 200	a,b,c	2	1:20,000	Photo	A,I,E,U,R
D10	Morden-Winkler (No. 18)	Pub. 1973	71 424	a,b,c	2	1:20,000	Photo	A,I,E,U,R
D11	Deep Lake	Int. 1975	1 400	a,b	1	1:6,000	B&W	R
D12	Thompson Environmental Study	Int. 1976	32	a,b	1	1:1,000	B&W	
D13	Organic Soil Study of Alexander L.G.D.	Int. 1975	29 456	a,b	3	1:63,360	B&W	A
D14	Winnipeg Region	Pub. 1975	280 000	a,b,c	2	1:20,000	Photo	A,E,U,R
D15	Brandon Region	Pub. 1976	59 600	a,b,c	2	1:20,000	Photo	A,E,U,R
D16	Boissevain-Melita (No. 20)	Pub. 1978	262 912	a,b,c	2	1:20,000	Photo	A,I,E,U,R
D17	Carman	Pre.	73 905	a,b	2	1:20,000	B&W	A,E,R
D18	Orr Lake	Int. 1977	20	a,b	1	1:1,000	B&W	
D19	Pelican-Rock Lake	Int. 1983	14 080	a,b	2	1:20,000	Photo	A,E,R,I
D20	West Portage	Int. 1982	120 956	a,b	2	1:20,000	Photo	A,I,E,R
D21	Minnewasta	Int. 1978	2 560	a,b	2	1:20,000	Photo	A,E,R,I
D22	Killarney	Int. 1979	4 600	a,b	2	1:20,000	Photo	A,E,R,I
D23	Matlock-Gimli-Riverton	Int. 1981	18 400	a,b	2	1:20,000	Photo	A,E,R,I
D24	Glenboro	Int. 1979	5 960	a,b	2	1:20,000	Photo	A,E,R,I
D25	Sandy Lake	Int. 1980	1 720	a,b	2	1:20,000	Photo	A,E,R,I
D26	Brokenhead	Int. 1979	10 813	a,b	2	1:20,000	Photo	A,E,R,I,U
D27	Rockwood	Int. 1980	12 928	a,b	2	1:20,000	Photo	A,E,R,I,U
D28	Oak Lake	Int. 1979	1 293	a,b	2	1:20,000	Photo	A,I
D29	Bird River	Int. 1980	2 560	a,b	2	1:20,000	Photo	A,E,R
D30	North Shore Lac du Bonnet	Int. 1980	2 400	a,b	2	1:20,000	Photo	A,E,R
D31	Grindstone Point	Int. 1979	8 040	a,b	2	1:20,000	Photo	A,E,R

SUMMARY OF SOIL SURVEY COVERAGE FOR MANITOBA (continued)
JANUARY, 1985

Map Project Designation	Name (Soil Report No.)	Report[1] Status	Area in Hectares	Map Unit[2] Description	Survey[3] Intensity Level	Map Scale	Map[4] Base	Land Evaluation[5] & Interpretations
D32	Paint Lake	Int. 1980	2 880	a,b	2	1:10,000	Photo	A,E,R
D33	Cranberry Portage	Int. 1980	80	a,b	1	1:5,000	Photo	A,E,R
D34	Dauphin	Int. 1981	6 400	a,b	2	1:20,000	Photo	A,E,R,I
D35	South Riding Mtn.	Pre.	23 488	a,b	2	1:20,000	Photo	A,E,R
D36	West Interlake	Int. 1981	10 036	a,b	2	1:20,000	Photo	A,E,I,R
D37	Swan R. Townsite	Pre.	7 680	a,b	2	1:20,000	Photo	A,E,R,I
D38	Hadashville-organic	Int. 1981	6 475	a,b	3	1:40,000	Photo	A,E,I,R
D39	Part of L.G.D. Stuartburn (Rat River)	Pre.	27 972	a,b	3	1:40,000	Photo	A,E,I,R
D40	Falcon L-Brereton L	Pre.	25 900	a,b	2	1:20,000	Photo	A,E,R
D41	Quesnel Lake-North Shore Winnipeg River	Pre.	3 000	a,b	2	1:20,000	Photo	A,E,R
D42	Duck Mountain	Int. 1982	3 036	a,b	2	1:20,000	Photo	A,E,R
D43	Spruce Woods	Pre.	26 300	e	3	1:40,000	Photo	A,E,R
D44	McGregor	Int. 1982	3 910	a,b	2	1:20,000	Photo	A,E,R
D45	Pine Creek	Int. 1983	1 942	a,b	2	1:20,000	Photo	A,E,R,I
D46	Arborg-Riverton	Int. 1982	2 590	a,b	2	1:20,000	Photo	A,E,R,I
D47	Roblin	Int. 1983	4 096	a,b	2	1:20,000	Photo	A,E,R,I
D48	Flin Flon	Pre.	4 600	a,b	2	1:20,000	Photo	A,E,R
D49	St. Anne-La Broquerie	Pre.	74 592	a,b	3	1:40,000	Photo	A,E,R,I
			4 662	a,b	2	1:20,000	Photo	A,E,R,I
D50	City of Brandon	Int. 1984	2 980	a,b	2	1:20,000	Photo	A,E,R,I
D51	Westbourne	Int. 1985	51,456	a,b	2	1:20,000	Photo	A,E,R,I
D52	Notre Dame, Rathwell, Treherne Townsites	Pre.	6 144	a,b	2	1:20,000	Photo	A,E,R,I
D53	Altona, Emerson, Gretna, Ile des Chenes, Landmark, Letellier, Rosenort, St. Jean Townsites	Int. 1984	14 080	a,b	2	1:20,000	Photo	A,E,R,I
D54	Russell, Binscarth-Townsites	Int. 1984	3 584	a,b	2	1:20,000	Photo	A,E,R,I
D55	St. Rose Du Lac-Townsite	Int. 1985	1 536	a,b	2	1:20,000	Photo	A,E,R,I
D56	Souris, Wawanesa, Virden, Townsites	Pre.	6 400	a,b	2	1:20,000	Photo	A,E,R,I
D57	Fraserwood, Inwood, Komarno Townsites, Lake Man. Shoreline	Pre.	1 856	a,b	2	1:20,000	Photo	A,E,R,I
D58	Hallboro, Minnedosa-Townsites	Data	4 544	a,b	2	1:20,000	Photo	A,E,R,I
D59	Beaudry Park	Data	640	a,b	2	1:20,000	Photo	A,E,R
D60	Portions of Dufferin, Grey, and South Norfolk	Data	68 488	a,b	2	1:20,000	Photo	A,E,R,I
D61	Meditation Lake	Data	3 072	a,b	2	1:20,000	Photo	A,E,R
D62	Wanipigow Lake	Data	8 960	a,b	2	1:20,000	Photo	A,E,R

SUMMARY OF SOIL SURVEY COVERAGE FOR MANITOBA (continued)
JANUARY, 1985

Map Project Designation	Name (Soil Report No.)	Report[1] Status	Area in Hectares	Map Unit[2] Description	Survey[3] Intensity Level	Map Scale	Map[4] Base	Land Evaluation[5] & Interpretations
D63	Shellmouth Resevoir	Pre.	3 130	a,b	2	1:20,000	Photo	A,E,R,I
D64	Assiniboine River	Pre.	4 095	a,b	2	1:20,000	Photo	A,E,R,I
D65	Villages of Hamiota, Strathclair, Rapid City	Pre.	2 175	a,b	2	1:20,000	Photo	A,E,R,I
D66	Springfield R.M.	Pre.	13 440	a,b	2	1:20,000	Photo	A,E,R,I
D67	St. Eustache, Springstein	Pre.	2 110	a,b	2	1:20,000	Photo	A,E,R,I
Reconnaissance Surveys								
R1	South Western (No. 3)	Pub. 1940	709 600	d	3	1:125,000	B&W	A
R2	South Central (No. 4)	Pub. 1943	967 600	d	3	1:125,000	B&W	A
R3	Winnipeg and Morris (No. 5)	Pub. 1953	1 419 200	d	3	1:125,000	Color	A
R4	Rossburn and Virden (No. 6)	Pub. 1956	1 372 400	d	3	1:125,000	Color	A
R5	Carberry (No. 7)	Pub. 1957	967 600	d	3	1:125,000	Color	A
R6	West-Lake (No. 8)	Pub. 1958	592 800	d	3	1:125,000	Color	A
R7	Grandview (No. 9)	Pub. 1957	689 200	d	3	1:125,000	Color	A
R8	Nelson River Basin (No. 10)	Pub. 1973	224 000	b	3	1:100,000	Color	A
R9	Fisher and Teulon (No. 12)	Pub. 1961	949 200	a,c	3	1:100,000	Color	A
R10	Swan River (No. 13)	Pub. 1962	316 000	a,c	3	1:125,000	Color	A
R11	South Eastern (No. 14)	Pub. 1964	749 200	a,c	3	1:125,000	Color	A,F
R12	Lac du Bonnet (No. 15)	Pub. 1967	764 800	a,c	3	1:125,000	Color	A,F,R
R13	Grahamdale (No. 16)	Pub. 1971	764 800	a,b	3	1:125,000	Color	A,F,U,R,E
R14	Red Rose-Washow Bay (No. 19)	Pub. 1975	704 400	a,b	3	1:125,000	Color	A,F
R15	Boissevain-Melita (No. 20)	Pub. 1978	299 520	a,b	2	1:40,000	Photo	A,I,E
R16	Ste. Rose (No. 21)	Pub. 1981	676 705	a,b	3	1:125,000	Color	A,I,R,E,F
R17	Waterhen	Pre.	949 600	a,b	4	1:125,000	B&W	A
R18	Swan Lake	Data	599 200	a,b	3,4	1:125,000	B&W	A
R19	The Pas (No. 22)	Pub. 1982	791 700	a,b	4	1:125,000	Color	A,I,E,R,F
R20	Grand Rapids	Pre.	675 031	a,b	4	1:125,000	B&W	A
R21	Cormorant	Int. 1975	920 000	a,b	4	1:125,000	B&W	A
R22	Wekusko	Pre.	1 400 000	a,b	4	1:125,000	B&W	A
R23	Pointe du Bois	Data	740 000	a,b				
R24	Roseau River	Pub. 1977	45 200	a,b	3	1:63,360	B&W	A
R25	Red Deer Lake	Pub. 1966	34 860	a,b	2	1:31,680	Photo	A
R26	Cross Lake and Norway House	Pre.	615 200	a,b	4	1:125,000	B&W	A
R27	South Central - Escarpment	Pre.	107 744	a,b	2,3	1:40,000	Photo	A,E,R
R28	Pasquia Lake	Pub. 1984	2 330	a,b	3	1:50,000	B&W	A,E
R29	Lorne R.M.	Pre.	512	a,b	2	1:20,000	Photo	A,E,R,I
			4 608	a,b	2	1:20,000	Photo	A,E,R,I
			54 528	a,b	3	1:50,000	N.T.S.	A,E,R,I
R30	Swan River R.M.	Pre.	18 432	a,b	3	1:50,000	Photo	A,E,R,I

SUMMARY OF SOIL SURVEY COVERAGE FOR MANITOBA (continued)
JANUARY, 1985

Map Project Designation	Name (Soil Report No.)	Report[1] Status	Area in Hectares	Map Unit[2] Description	Survey[3] Intensity Level	Map Scale	Map[4] Base	Land Evaluation[5] & Interpretations
Biophysical and Exploratory Surveys								
B1	Lake Winnipeg, Churchill & Nelson Rivers	Pub. 1973	3 600 000	e	4	1:250,000 1:50,000	B&W	
B2	Churchill Transportation Corridor	Data 1974	179 000	f	4	1:125,000	B&W	
B3	54C Hayes River	Int. 1976	1 370 300	f	4	1:125,000	B&W	
B4	54D Kettle Rapids	Int. 1976	1 370 300	f	4	1:125,000	B&W	
B5	52M Carrol Lake	Int. 1977	634 000	f	4	1:125,000	B&W	
B5	62P Hecla	Int. 1977	466 200	f	4	1:125,000	B&W	
B6	53D Deer Lake	Int. 1978	629 700	f	4	1:125,000	B&W	
B6	63A Berens River	Int. 1978	848 500	f	4	1:125,000	B&W	
B7	53M Knee Lake	Int. 1978	1 405 900	f	4	1:125,000	B&W	
B8	53L Oxford House	Int. 1978	1 441 100	f	4	1:125,000	B&W	
B8	63H Norway House	Data	540 800	f	4	1:125,000	B&W	
B9	SE 1/4 64A Split Lake	Int. 1979	342 400	f	4	1:125,000	B&W	
B9	63P Sipiwesk	Int. 1979	1 405 900	f	4	1:125,000	B&W	
B10	53E Island Lake	Pre.	1 286 900	f	4	1:125,000	B&W	
E1	Surface Deposits & Soils of Northern Manitoba	Int. 1963		g	5	1:1,267,000	B&W	
E2	Exploratory Terrain Study of Northern Manitoba and Southern Keewatin, N.W.T.	Int. 1974		g	5	1:1,000,000	B&W	

1.Report Status
Pub.-Published Report and Map
Int.-Interim Report and Map Available
Pre.-Preliminary Map and Legend Available
Data-Field Data Available Only

2.Map Unit Descriptions Code
a-single series and phases
b-series complexes defined as to proportion
c-series complexes undefined as to proportion
d-associations
e-biophysical units (materials and physiography)
f-biophysical units (associations & complexes of associations)
g-regional and local physiographic units

3.Survey Intensity Levels

Code	Name	Scale	Minimum Size Delineation(ha)	Inspection Density (Approx. range)
1	Very detailed	>1:12,000	<1.5	>1 per 3 ha
2	Detailed	1:12,000 to 1:40,000	1.5-16	1 per 3 to 50 ha
3	Semi-detailed	1:40,000 to 1:125,000	16 to 256	1 per 10 to 1 000 ha
4	Reconnaissance	1:125,000 to 1:250,000	256 to 625	1 per 100 to 110 000 ha
5	Exploratory	1:250,000 to 1:1,000,000	625 to 110 000	1 per 300 to 500 000 ha

4.Published Map Base Code

Photo-Photomosaic
B&W -Black and white line
Color-Colored line

5.Interpretations Code

A-Agriculture Capability
E-Engineering
F-Forestry
I-Irrigation Suitability
U-Urban Planning and Community Development
R-Recreation

TOTAL HECTARAGE COVERED

	1984	To Date
Initial Reconnaissance	2,330	18,619,436
Initial Detailed survey	---	16,460
Detailed Resurvey	167,424	1,847,163
Biophysical Survey	---	12,521,000

Published Reports, Maps, Interim Reports, available from:

Queen's Printer,
Publications Branch,
Manitoba Archives Bldg.,
200 Vaughan St.,
Winnipeg, Manitoba,
Phone:945-3103

Detailed Surveys of Winnipeg Region and Brandon Region:

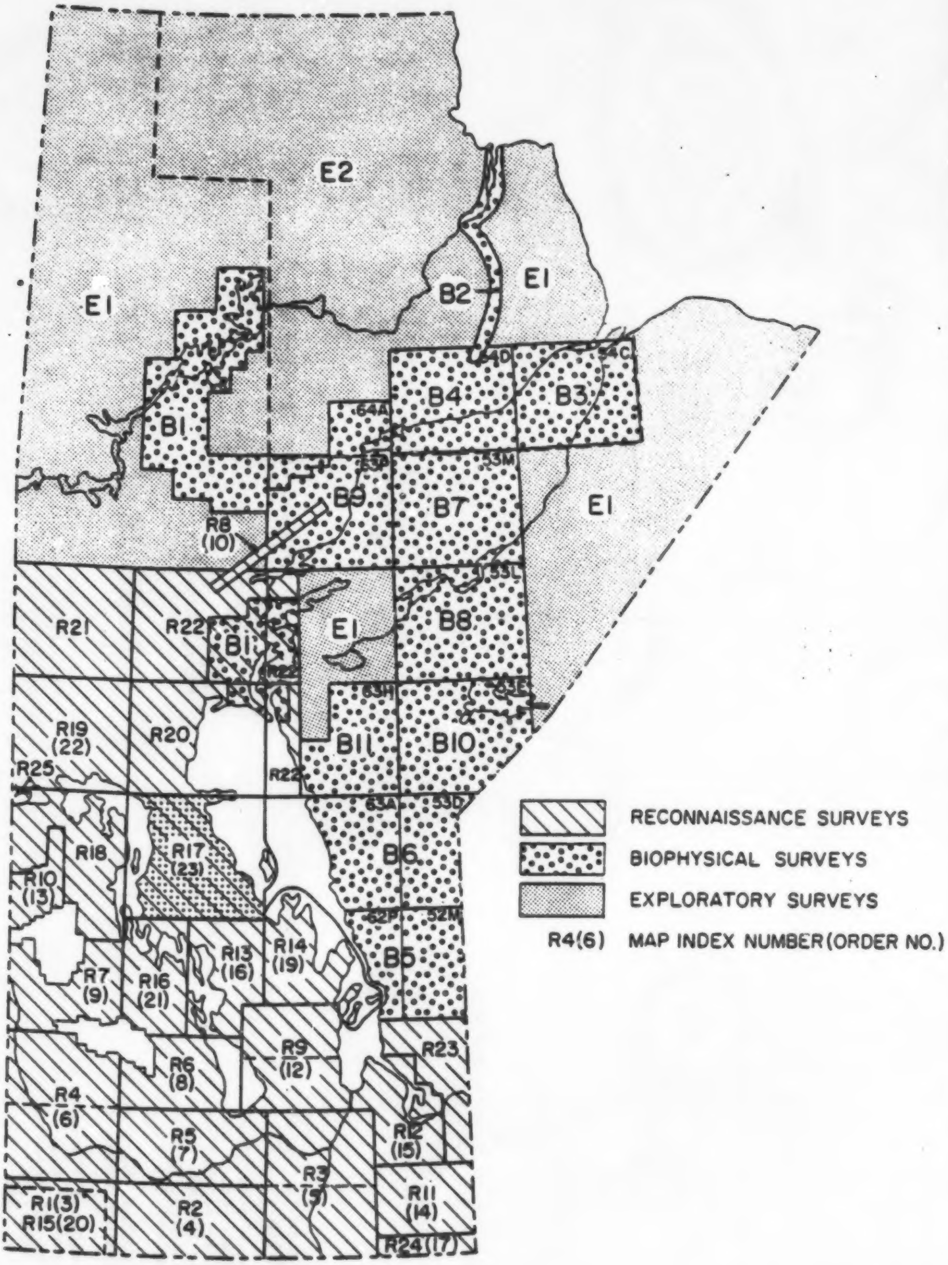
Municipal Planning Branch
Manitoba Dept. of Municipal Affairs
1418-405 Broadway Ave.,
Winnipeg, Man., R3C 3L6
Phone: 945-2150

Preliminary Map and other field data available from:

Canada-Manitoba Soil Survey Office,
Dept. of Soil Science University of Manitoba
Winnipeg, Man., R3C 1T5
Phone: 474-8153

Biophysical Land Classification Maps and Reports

Surveys and Mapping Branch
Century Industrial Branch
989 Century Plaza
Winnipeg, Man., R3H 0W4
Phone: 945-6666


E2
E1
B2
E1
B1
B4
B3
64A
54D
54C
63P
53M
B9
B7
E1
R8
(10)
53L
R21
R22
B1
E1
B8
R22
63H
53E
R19
(22)
R20
B11
B10
R25
R22
63A
53D
R18
R17
(23)
B6
R10
(13)
62P
52M
R7
(9)
R16
(21)
R13
(16)
R14
(19)
B5
R23
R9
(12)
R6
(8)
R4
(6)
R5
(7)
R12
(15)
R3
(5)
R11
(14)
R1(3)
R15(20)
R2
(4)
R24(17)
RECONNAISSANCE SURVEYS
BIOPHYSICAL SURVEYS
EXPLORATORY SURVEYS
R4(6) MAP INDEX NUMBER (ORDER NO.)

LOCATION OF RECONNAISSANCE AND BIOPHYSICAL SURVEYS

Figure 1

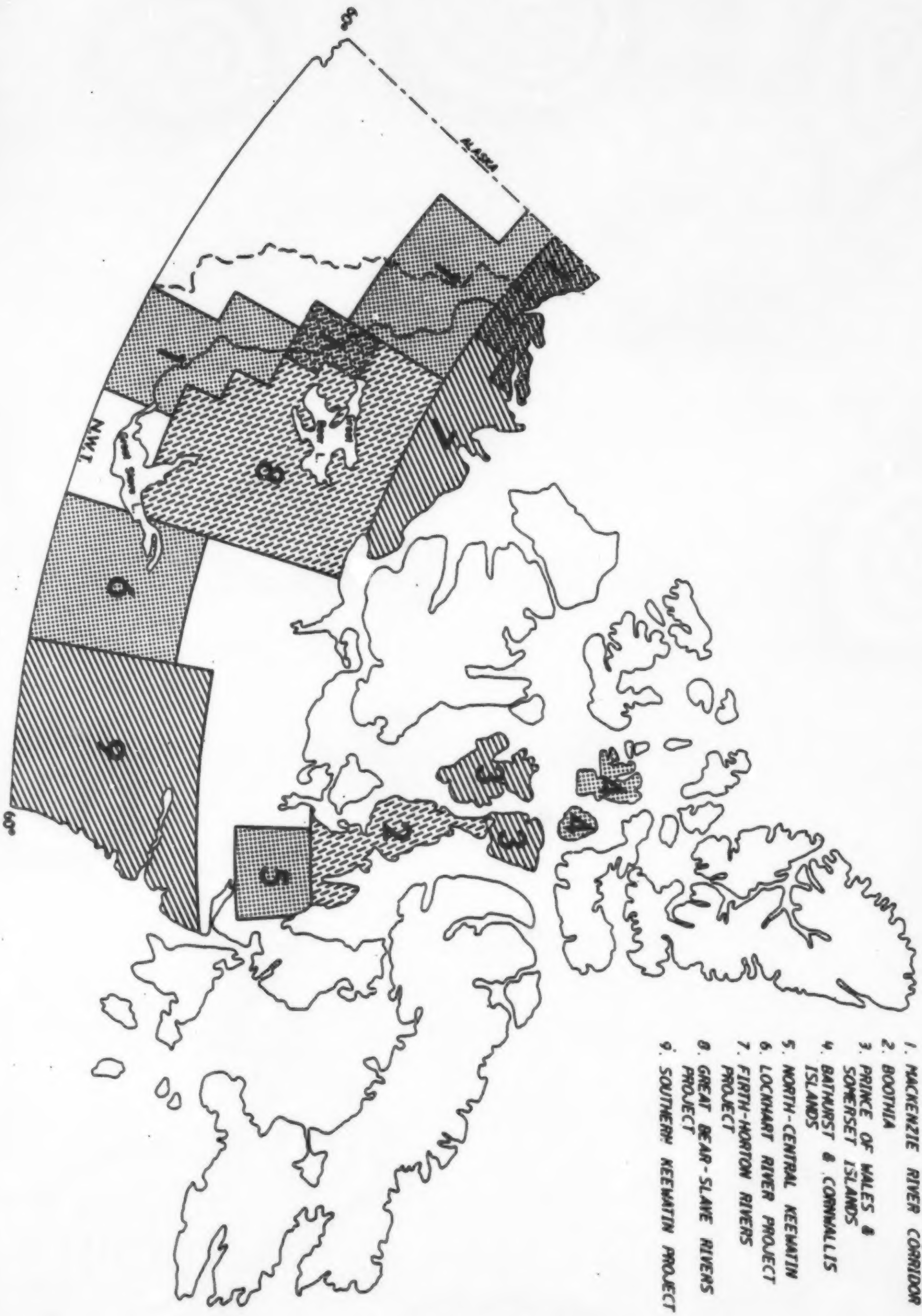

1. MACKENZIE RIVER CORRIDOR
2. BOOTHIA
3. PRINCE OF WALES & SOMERSET ISLANDS
4. BATHURST & CORNWALLIS ISLANDS
5. NORTH-CENTRAL KEEWATIN
6. LOCKHART RIVER PROJECT
7. FIRTH-HORTON RIVERS PROJECT
8. GREAT BEAR-SLAVE RIVERS PROJECT
9. SOUTHERN KEEWATIN PROJECT
ALASKA
N.W.T.
60°
69°
1
2
3
4
5
6
7
8
9

Figure 2. N.W.T. Projects: Reports, Maps and Available Data.